A HEYWOOD PUBLICATION

British Chemical Engineering

THE JOURNAL DEVOTED TO THE TECHNIQUES OF CHEMICAL ENGINEERING APPLIED TO INDUSTRY

August/September 1959
Vol. 4 Nos. 8 and 9

Editor:
J. O. S. MACDONALD, B.Sc., A.R.I.C., A.M.I.Chem.E.

Associate Editor:
I. BERKOVITCH, Ph.D., F.R.I.C., A.M.I.Chem.E.

Assistant Editor:
WILLIAM D. CLIFFORD

A view of a large 5 ft diameter Podmore-Boulton Vibro-energy Mill manufactured by William Boulton Ltd., Stoke-on-Trent. This batch set-grinding mill is capable of reducing very hard materials to submicron sizes.

BRITISH CHEMICAL ENGINEERING is published monthly by HEYWOOD & CO. LTD., Drury House, Russell Street, Drury Lane, London, W.C.2 (Tel.: TEMple 3422), on the 20th of the preceding month. Annual subscription £2 U.K., £2 10s. 0d. sterling overseas for 12 issues post free ($7.50 U.S.A. and Canada) or by standing order through newsagents at 2s. 6d. a copy net. BRANCH OFFICE: Royal Buildings, 2 Mosley Street, Manchester, 2. Tel.: Central 9935 © Heywood & Co Ltd., 1959. Must not be reproduced without written permission.

MAIN ARTICLES

Grinding at Supercritical Speeds — *by R. T. Hukki, Sc.D., M.I.M.E.* — 446
Broyage à vitesses surcritiques
Die Zerkleinerung bei überkritischen Geschwindigkeiten
Измельчение при сверхкритических скоростях

An Experimental Investigation of Vibration Milling — 450
by H. E. Rose, D.Sc. (Eng.), Ph.D., M.I.Mech.E., M.I.C.E., and R. M. E. Sullivan, B.Sc. (Eng.)
Etude expérimentale du broyage vibratoire
Experimentelle Untersuchung von Vibrationsmühlen
Экспериментальное исследование вибрационного дробления

Dry Grinding and Dry Magnetic Separation of Magnetic Iron Ores — *by Edvin B. Johanson* — 458
Le broyage à sec et la séparation magnétique à sec du magnétite
Trockenzerkleinerung und trockene magnetische Trennung von Ferrooxyden
Сухое измельчение и сухое магнитное разделение магнетита

Calculation of Closed-circuit Grinding — *by R. L. Brown, M.A., F.Inst.P., F.Inst.F.* — 463
Calcul du broyage à circuit clos
Berechnung der Zerkleinerung im geschlossenen Kreislauf
Расчет дробления в замкнутом цикле

Comminution Theory and Practice — *by J. Kelleher, M.Sc., A.R.I.C.* — 467
Théorie et pratique de la comminution
Theorie und Praxis der Zerkleinerung
Теория и практика измельчения

OTHER FEATURES

Leader: Investment for Automation 445
Production Scheme for Erdoelchemie 462
Safety, Health and Welfare 466
Warren Spring Laboratory 474
American Letter: The Fifth World Petroleum Congress 476
Nomogram: Viscosities of Slurries by D. S. Davies 478

REGULAR FEATURES

Digest 439
Process Engineer's Notebook 480
World of Chemicals 482
Book Reviews 484
Plant Equipment News 488
Month's News in Brief 498

Résumés

B.C.E., 4, Nos. 7 and 8, 446. U.D.C. No. 621.926.5.

BROYAGE À VITESSES SURCRITIQUES

par R. T. Hukki

L'auteur préconise l'emploi du broyage surcritique dans les cas où le matériau à broyer est également le moyen de broyage. Cette thèse est appuyée par des expériences à l'échelle pilote employant des vitesses surcritiques au-dessus de 230% et par des travaux pratiques employant des vitesses légèrement surcritiques, notamment sur des minerais de cuivre silicieux.

B.C.E., 4, Nos. 7 and 8, 450. U.D.C. No. 621.926.9.

ÉTUDE EXPÉRIMENTALE DU BROYAGE VIBRATOIRE

par H. E. Rose et R. M. E. Sullivan

Un aperçu est donné des resultats obtenus avec un broyeur vibratoire employant des composantes verticales et horizontales de mouvement. Ces resultats indiquent qu'il est possible d'obtenir des vitesses de broyage très élevées avec une dépense d'energie minime. Les vitesses de broyage les plus élevées sont obtenues avec des vibrations à haute frequence et des amplitudes relativement petites. Un haut niveau de chargement du broyeur et l'emploi des moyens de broyage de haute densité favorisent également les vitesses de broyage élevées.

B.C.E., 4, Nos. 7 and 8, 458. U.D.C. No. 621.926.7: 621.928.8.

LE BROYAGE À SEC ET LA SÉPARATION MAGNÉTIQUE À SEC DU MAGNÉTITE

par Edvin B. Johanson

Les installations pour le broyage à sec employant des broyeurs Aerofall et des séparateurs magnétiques sont discutés en détail. Dans le cas des separateurs magnétiques, on a décrit quelques combinaisons possibles en indiquant leur construction et leur mode operatoire.

B.C.E., 4, 7 and 8, 463. U.D.C. No. 621.928.1:512.831.

CALCUL DU BROYAGE À CIRCUIT CLOS

par R. L. Brown

L'auteur décrit l'application de l'algèbre des matrices à la construction d'un broyeur-classificateur combiné. Les calculs sont basés sur la connaissance de la granulometrie du matériau chargé, le rendement de la classification et la dégradation atteinte par le broyeur pour chaque classe du matériau, ces classes étant traités séparement.

B.C.E., 4, 7 and 8, 467. U.D.C. 621.926

THÉORIE ET PRATIQUE DE LA COMMINUTION

par J. Kelleher

Une revue des principes de sélection et d'opération des installations de broyage, ainsi que du calcul de leurs besoins énergétiques. Des exemples élaborés sont cités pour illustrer ces principes et les differentes théories concernant la reduction de la granulométrie sont passées sous examen critique.

Kurzreferate

B.C.E., 4, Nos. 7 and 8, 446. U.D.C. No. 621.926.5.

DIE ZERKLEINERUNG BEI ÜBERKRITISCHEN GESCHWINDIGKEITEN

von R. T. Hukki

Der Autor empfiehlt die Anwendung von überkritischer Zerkleinerung in Fällen, wo das zu zerkleindernde Material gleichzeitig das Zerkleinerungsmaterial darstellt. Diese Ansicht wird von Untersuchungsarbeiten im halbindustriellen Massstab bei Anwendung von überkritischen Geschwindigkeiten von über 230%, sowohl als von praktischen Arbeiten bei niedrigen überkritischen Geschwindigkeiten, insbesondere mit Kieselkupfererzen, unterstützt.

B.C.E., 4, Nos. 7 and 8, 450. U.D.C. No. 621.926.9

EXPERIMENTELLE UNTERSUCHUNG VON VIBRATIONSMÜHLEN

von H. E. Rose und R. M. E. Sullivan

Die Ergebnisse einer Vibrationsmühle mit Benutzung von senkrechten und horizontalen Bewegungskomponenten werden beschrieben. Die Ergebnisse zeigen, dass sehr hohe Mahlgeschwindigkeiten mit sehr kleinem Energieaufwand erreicht werden können. Die höchsten Mahlgeschwindigkeiten werden durch Vibrationen von hoher Frequenz mit kleineren Amplituden gegeben. Hohe Füllung der Mühle sowie die Benutzung von Zerkleinerungsmaterialen von hoher Dichte tragen ebenfalls zu hohen Mahlgeschwindigkeiten bei.

B.C.E., 4, Nos. 7 and 8, 458. U.D.C. No. 621.926.7: 621.928.8.

TROCKENZERKLEINERUNG UND TROCKENE MAGNETISCHE TRENNUNG VON FERROOXYDEN

von Edvin B. Johanson

Trockene Zerkleinerungsanlagen mit Anwendung von Aerofall-Mühlen und magnetischen Trennaparaten werden eingehend beschrieben. Für die Letzteren werden verschiedene Zusammenstellungen, ihr Aufbau und Betriebsweise angegeben.

B.C.E., 4, 7 and 8, 463. U.D.C. No. 621.928.1:512.831

BERECHNUNG DER ZERKLEINERUNG IM GESCHLOSSENEN KREISLAUF

von R. L. Brown

Die Anwendung der Matrizenalgebra für die Planung eines Mahl- und Klassieraggregates wird beschrieben, wenn die Siebanalyse des Aufgabegutes, die Klassiererleistung und die von der Mühle in jeder Korngrössenfraktion erreichte Zerkleinerung bei getrennter Beschickung bekannt sind.

B.C.E., 4, 7 and 8, 467. U.D.C. 621.926

THEORIE UND PRAXIS DER ZERKLEINERUNG

von J. Kelleher

Die Grundsätze der Auswahl und des Betriebs von Mahlanlagen sowie der Berechnung ihres Energieaufwands werden beschrieben. Ausgearbeitete Beispiele zur Erläuterung dieser Grundsätze werden angegeben und die verschiedenen Theorien der Korngrössenverringerung werden kritisch betrachtet.

Резюме

B.C.E., 4, Nos. 7 and 8, 446. U.D.C. No. 621.926.5

ИЗМЕЛЬЧЕНИЕ ПРИ СВЕРХКРИТИЧЕСКИХ СКОРОСТЯХ

Р. Т. Хукки.

Автор рекомендует применение сверхкритического измельчения в тех случаях, когда измельчаемый материал является также и измельчающим материалом. Мнение автора подтверждается исследовательскими работами в полупромышленном масштабе с применением сверхкритических скоростей свыше 230%, а также практическими работами при низких сверхкритических скоростях, в частности на кремнистой медной руде.

B.C.E., 4, Nos. 7 and 8, 450. U.D.C. No. 621.926.9

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ВИБРАЦИОННОГО ДРОБЛЕНИЯ

Х. Э. Роз и Р. М. Э. Сюлливан.

Описаны результаты работы вибрационной дробилки, употребляющей как вертикальные, так и горизонтальные компоненты движения. Полученные результаты указывают, что существует возможность достичь весьма высоких скоростей дробления при очень малом расходе электроэнергии. Высочайшие скорости измельчения достигаются высокочастотными вибрациями с умеренно малыми амплитудами. Высокий уровень загрузки и употребление измельчающей среды высокой плотности также способствуют большим скоростям измельчения.

B.C.E., 4, Nos. 7 and 8, 458. U.D.C. No. 621.926.7: 621.928.8.

СУХОЕ ИЗМЕЛЬЧЕНИЕ И СУХОЕ МАГНИТНОЕ РАЗДЕЛЕНИЕ МАГНЕТИТА

Эдвин Б. Йоганссон.

Подробно обсуждается вопрос о сухих измельчительных установках с применением дробилок «Аэрофолл» и магнитных разделителей. Для последних описан ряд возможных комбинаций, а также подробности их конструкции и действия.

B.C.E., 4, 7 and 8, 463. U.D.C. No. 621.928.1:512.831

РАСЧЕТ ДРОБЛЕНИЯ В ЗАМКНУТОМ ЦИКЛЕ

Р. Л. Браун.

Описано применение алгебры матриц к конструкции аггрегата дробилки и классификатора при заданных: ситовом составе сырья, эффективности классификации и степени измельчения, достигнутой дробилкой для каждой фракции сырого материала при отдельной подаче.

B.C.E., 4, 7 and 8, 467. U.D.C. 621.926

ТЕОРИЯ И ПРАКТИКА ИЗМЕЛЬЧЕНИЯ

Дж. Келлехэр

Рассматриваются различные способы измельчающих приспособлений, режима их работы и расчета их энергоемкости. Приводятся примеры разработанных задач для пояснения описанных способов. Различные теории о понижении размеров частиц подвергаются критическому исследованию.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Revised Scheme for Full-time Course Issued

A HAPPY blend of re-thinking of fundamentals and hard-headed attention to practical experience, including economics, seems to characterise the new scheme for a full-time course issued by the Institution of Chemical Engineers. Amending the earlier view that chemistry, physics and mathematics should dominate the earlier two years of training, the Institution now stresses that chemical engineering topics should be a part of the degree or sandwich course from the first day.

To match advances in scientific knowledge, the "philosophy" of the course has altered. "Post-war developments of chemical engineering" states an explanatory note "have emphasised the mathematical-analytical aspects of the subject and it has become increasingly clear that we are no longer dealing with a series of unconnected 'unit operations' but instead with certain groups of processes which depend upon the same or related physical phenomena, the study of which forms a logical thread on which to string the individual processes. Thus filtration, sedimentation, pneumatic conveying, fluidisation, etc., can all be regarded as aspects of particle-fluid motion." At the same time, practical experience at a works, possibly on the Continent, is recommended as an essential adjunct. But stress on economics as well as scientific principles is more than an adjunct. The scheme recommends that the economic aspect should be introduced into the lectures on chemical process principles in the first year, with special attention to the principle of securing economic balance between opposing factors to determine the most economically sized unit.

We understand that the document is intended to bring together views on the changing emphasis in chemical engineering education not to impose a syllabus on colleges and universities; accordingly, a course based largely on the previous scheme could carry complete exemption from the Institution's examination. It appears that the main aim is to develop advanced thinking on the nature and relative importance of subjects which should be part of a chemical engineering course.

Man Against Mussel

OPERATING a cooling system at a coastal refinery involves more than knowledge of engineering and human relations. D. H. TULLIS, *et al* have described in a paper (*J. Inst. Petroleum*, Vol. 45, No. 426, p. 155) their battles with invading organisms illustrated with photographs and a biological sketch of the black edible mussel, *Mytilus Edulis*. To control slime provision had been made in the design of Coryton refinery for chlorination of the once-through salt water cooling system. After commissioning of the refinery, however, it soon became evident that there remained a major problem of controlling growth of marine macro-organisms. The most important of these was the mussel. To control it, MR. TULLIS and his colleagues had to arrange a literature search into its life and habits, as well as a survey of the variation in chlorine demand of the Thames water with the state of the tide and season. The solution appeared to be discontinuous injection of chlorine during the summer mussel breeding season of May-October for two 50-minute periods, one 2½ hours before and the other one hour after high tide, with winter injection for 50 minutes at high tide.

A dosage of between 7 and 8 p.p.m. is aimed at, and a total available chlorine content of between 2 and 3 p.p.m. at the water intake is considered satisfactory. The purpose of the chosen double injection during the summer is to leave less time for the development of larvae entering the cooling water system between chlorination periods; it also increases the total chlorination period. The timing is to coincide with a period of relatively low chlorine demand by the river water.

In addition, static chlorination tests on this system have indicated that a 100% kill of mussels growing within the line can be achieved. Consequently, changes have been made in the line connections to make it possible to take out of service any one intake line, static chlorinate this line for a period of 7–10 days, and then flush out at full bore. It was estimated that static chlorination and flushing were necessary every two years, with full-bore flushing every year for silt removal. The published discussion on this paper showed that many operators were having to study this destructive branch of bio-engineering.

WE regret that, owing to the recent dispute in the printing industry, it was not possible to publish our normal August and September issues. In order to maintain the continuity of the volume, these two issues have been combined.

Arrangements are being made to extend readers' subscriptions to compensate for the loss of an issue.

Spaced Sheet Metal Packing for Columns

AFTER a critical examination of existing types of distillation columns, G. ADOLPHI and R. FLEISCHER put forward in 1955* suggestions for a new design of packing based on bundles of spaced sheet metal plates disposed vertically. In a recent paper† R. FLEISCHER has now briefly reported the first operating results with this packing. The upper parts of the sheets are slightly bent over to guide the falling condensate on to the surface and prevent the drops from falling between the plates. This produces a trickling film on the plates.

Tests were carried out on a 24 m. high discontinuous column of 400 mm. diameter with 12 mm. spacing between the plates, distilling cyclohexanone-cyclohexanol. Capacity was defined as distillate (final products) in litres per hour of distillation per cu. m. volume of the column shell. On this basis the new packing gave a figure of 48.5 l/cu. m. hr. against 7.5 for a bubble cap column. Pressure drop in the column was 21 mm. w.g./m. compared with 132 for the bubble-cap type which meant that the still temperature was reduced from 120°C in the latter case to 81°C with the new design. In both cases temperature at the head of the

column was maintained at 54°C. DR. FLEISCHER points out that the increase in capacity can make for considerable economies in material, preparation and assembly costs since the column cross-sectional area can be so greatly reduced for a given throughput.

It is interesting also to note a different method of approach to reducing pressure drops in columns reported in *Ind. Eng. Chem.* 1959, Vol. 51, No. 5, p. 619. In this a horizontal fractionating device was reported to give a low-pressure drop at high liquid and vapour loadings and with good efficiencies.

* *Chem. Techn.*, 1955, Vol. 7, p. 638.
† *Chem. Techn.*, 1959, Vol. 11, p. 245.

Against Corrosion

"AN up-to-date exposition of knowledge of many aspects of corrosion" for the ferrous metals; this is the proud description of their sixth report by the Corrosion Committee of the British Iron and Steel Research Association. Their last report appeared 20 years ago. In the interim the committee have obtained reliable data by field tests and service trials for the corrosion rates of ferrous metals in air, soil and water. In particular they state that effects on the corrosion rate of differences in the composition of the metal and in the climatic conditions, such as relative humidity and atmospheric pollution, are now much more fully understood. Principles governing the successful protection of steel by painting have been established. Correct surface preparation of the metal for painting has been shown to be of supreme importance. They have also developed and published formulations of reliable priming paints, both for atmospheric and marine work. There are now authoritative figures for the performance of various types of coating in a range of exposure conditions.

Some of this information you can read directly in the indexed report or can follow up in the extensive list of references. But when in doubt it is useful to recall that B.I.S.R.A. also have a Corrosion Advice Bureau. Services are normally available without charge to members unless extensive experimental work is involved; non-members may use the Bureau on payment of a fee.

Air-Cooled v. Water Cooled

THE fears expressed in some quarters in the U.S. that shortage of water may prevent industrial expansion in that country seem unduly pessimistic; what is certain is that water for industrial purposes will have to be used over and over again and through the treatment required to make this possible, its cost will rise continuously. In this country, while the problem of industrial water supply is much less acute, its scarcity is increasing and the Americans' approach is therefore of some relevance.

This problem has a great deal to do with the wider use of air-cooled equipment. Nevertheless voices have been raised advising against the premature boarding of the "air-cooled band-wagon" and urging greater attention to the way in which industry uses water. Another approach is to seek alternative supplies of water and since water for cooling does not need to conform to the same standards of purity as potable water, the use of reclaimed sewage has been proposed. One plant, notably a refinery at Amarillo, uses some four million gallons per day of reclaimed sewage. There are, of course, objections to its use. To make it suitable as a coolant it must be surface non-fouling, which means the installation of equipment for settling, clarifying and filtering. There is also the hazard that incompletely treated water may contaminate the main water supply at a plant.

D. Q. KERN is among those who are more concerned with the way in which water is used by the processing industries. He points out that most process plants are designed for the limiting summer or winter conditions however briefly these may obtain, and he outlines the troubles which can occur with cooling equipment in wintertime. One of these was outlined in detail by KERN in an article published in this journal in April of this year. He shows that in a distillation plant a sharp decrease in cooling-water temperature can result in loss of efficiency of the upper plates of a column which will in turn lead to a lower purity of overhead product and an increased steam demand at the reboiler.

The remedy of throttling the water supply so as to maintain the condensate temperature nearer its design figure may lead to such low velocities that fouling occurs. To avoid snags of this kind KERN* proposes a constant velocity cooling water supply through the condensers of distillation plant to suppress fouling, including the case where cooling water is used for pressure control. Although the idea requires a pump, a flow controller, and some extra pipework the cost of this should be more than compensated for by the greater economy in water usage, in plant performance, and lengthened operating period through reduction in fouling.

* *Chemical Engineering* (10th August), 1959.

Properties of Polypropylene

PORTENT for the future was the fact that the only two papers on polyolefines at the London Plastics Convention were both devoted to polypropylene. J. M. GOPPEL of the Koninklijke/Shell Laboratorium reviewed their mechanical and physical properties while G. CAMPBELL of I.C.I. dealt with moulding characteristics. For characterisation of these polymers MR. GOPPEL advised classification by crystallinity, molecular weight and molecular weight distribution. By means of viscosity measurements the latter two properties can be directly related to the ease of processing of the materials.

However the molecular structure of polypropylene differs from that of polythene and MR. CAMPBELL pointed out that a different approach is therefore required in selecting moulding conditions. Rigidity equal to that of high-density polythenes is obtained at very much lower crystallinity. The flow of molten polypropylene is appreciably stiffer, or more viscous, than that of polythene but is influenced to a greater degree by changes in temperature and pressure in the moulding machine. High tensile modulus at elevated temperatures permits short cooling periods in the mould. Mould shrinkage is less than that of polythenes and as a result of the relatively small difference between lengthwise and transverse shrinkages, warpage problems are much reduced. These, and other characteristics of polypropylene, were discussed in relation to the choice of conditions for obtaining optimum properties in moulded articles.

New Formaldehyde Process

PROCESSES using methane as a starting material continue to attract research workers. Typical chemicals in heavy demand derived from methane include acetylene, methyl chloride and formaldehyde. In the case of formaldehyde, which is obtained mainly by the direct oxidation of methanol (75% of the world total), through rising output of synthetic resins and materials like pentaerythritol, there is an especially heavy demand.

So far the hydrocarbon routes for formaldehyde have not been outstandingly successful mainly because the yields are not much higher than 20% and a high concentration of methanol and appreciable quantities of acetaldehyde are

usually produced. Nevertheless, in countries with ample supplies of natural gas efforts are being made to improve these processes. Thus improvements in yields are claimed for a direct process route developed in Russia. Unlike its predecessors which have employed mixed phosphate metal oxide catalysts, this one uses nitric oxide. In the pilot plant work, carried out with a stainless-steel tubular reactor of diameter just over 1½ in. and a length of some 7 ft, conversions of methane to formaldehyde as high as 70% have been quoted. The best yields have been obtained with air to methane ratios in the range of 2 : 1 to 10 : 1. The gas throughput in the case of the pilot plant was 13 cu.m. per hr the operating temperature was in the range of 600-800°C, catalyst concentration was approximately 0.1% and contact times were of the order of 1/10 sec.

A complete account of this pilot investigation is given by N. S. Enikolopyan and co-workers,* including a study of the effects of space velocity ratio variation, methane concentration, catalyst concentration and the effects of temperature.

* *Zh. Prikl. Khim.* 1959, 32, (4), 913-919.

Mixing Efficiency in Continuous Flow Systems

IN a batch process a perfectly homogeneous mixture can be obtained of two miscible liquids when agitation, with the help of diffusion if necessary, is maintained for a long enough period of time. In a continuous flow system, however, it may happen that perfect mixing can never be attained. There can be stagnant regions in the reservoir, part of the feed may go directly to the outlet, piston or plug flow may take place. In order to study the behaviour of such a system and the efficiency of mixing, one can consider the tank or reservoir to act as a damper to variations in feed composition. The mathematical treatment of this problem thus becomes similar to one performed on a capacity in a servo-mechanism circuit, where a transfer function exists, from which can be obtained transient or permanent responses. In a recent paper, A. CHOLETTE and LEONCE CLOUTIER* have defined models based on this approach for examining various mixing conditions in continuous flow systems. Differential equations are derived which take into account an effective volume of mixing, possible short-circuiting, hold-up time of the system, partial displacement or piston flow. The treatment is difficult to summarise—we would refer interested readers to the original paper—but it has the great practical advantage that the values of the different factors contained in the integrated equations can be determined experimentally by the response of a given system to a sudden change in composition of the feed. It also leads to a design procedure for tank flow reactors when partial mixing occurs.

* *Canadian Journal of Chemical Engineering*, 1959, Vol. 37, No. 3, p. 105.

Thin Films Increase Evaporation Rates

AT the June meeting of the American Society of Mechanical Engineers, E. L. LUSTENADER and colleagues reported results of a programme undertaken to evaluate a new concept in heat transfer in which the over-all resistance to heat flow is decreased through the combined use of thin films both for evaporation and condensation. The thin films for evaporation were achieved by spreading the fluid on the surface by means of a slowly rotating wiper. Thin films for condensation resulted from the utilisation of surface tension. A vapour compression-type evaporator, using water as a heat-transfer fluid, was used to investigate the parameters involved. Over-all heat-transfer coefficients as high as 8000 Btu/hr. sq. ft °F were reached. Apparatus consisted of a heat-transfer surface, a vapour compressor and a rotating wiper. The heat-transfer surface, upon which water is evaporated and condensed, was a copper tube 24 in. long and 3 in. in diameter with a wall thickness of 0.035 in. Round the copper tube was a concentric 6 in. Pyrex glass tube wrapped with nichrome ribbon and electrically heated to prevent the formation of condensation on the inner glass surface. A glass tube was selected to allow observation of the condensing surface.

Inside the centre tube a wiper rotated about the vertical axis of the cylinder and secured to the top of the wiper shaft was a water distributor discharging water to the inner wall just in advance of the wiper. Thus the liquid was spread by the wiper into a thin film. As this evaporated, the vapour was drawn off and transported to the outer annular chamber by means of a compressor. The compressed vapour, which was superheated, was then used as a heating medium.

Details of this ingenious approach are in A.S.M.E. Paper No. 5—SA-30. The authors considered that results were applicable to the design of compact and economically operating process equipment. Sea-water tests showed that the slowly rotating wiper retards the formation of scale on the evaporating surface. The absence of bubbling in the thin film minimises brine carry-over and as a result a high purity condensate was produced.

More Uses for Isotopes, But No Regulations Yet

HOW soon will the regulations be issued for safeguarding industrial workers against the effect of ionising radiations? There is at present guidance for the use of sealed sources available in the "Preliminary Draft of the Factories (Ionising Radiations) Special Regulations" published in July, 1957, for consideration but these have no legal force. The great majority of the *open* sources used in industry are already covered by the "Factories (Luminising) Special Regulations, 1947." But in factories the major use of radioactive material is as sealed sources. We understand that both of these sets of regulations are being revised but we would suggest that the matter is pressed ahead urgently. Use of these valuable aids is increasing fast. In the current Annual Report of the Atomic Energy Authority it is stated that the total sales of radioisotopes and related products despatched from Harwell and Amersham rose to £800,000 for the year 1958-59 compared with £650,000 for the previous year. Examples are given of new applications of radioisotopes. They include a method of testing industrial filters with sized and labelled particulates. This method measures within 1% the quantity of particles passing filters having up to 90% efficiency. In addition a gas analyser operating at temperatures up to 350°C has been developed for measuring small leakages from systems; it uses an ionisation chamber filled with the gaseous mixture to be analysed. Tritiated water has proved highly successful in investigating problems of drying and for tracer work on water flows.

It is significant that the first commercial radiation monitoring and tracer services have now been launched (by Ekco Electronics and Elliott Automation) to carry out surveys or advise on tracer work.

Ball Flow Meter Controversy

SOME years ago a simple and cheap design of flow meter appeared consisting of a glass U-bend and a ball bearing. For a flow rate within the range of such an instrument the ball will come to rest upon the outer radius of the tube interior, through the equilibrium of three forces, the hydrodynamic, gravitational and a tangential friction force acting at the point of contact between ball and tube. The rate of

flow is denoted by the angle the ball makes with the perpendicular and the centre of the bend.

Recently SHULMAN and VAN WORMER proposed an equation correlating the rate of flow through such a meter to the position of the ball and other variables to which PROF. DANCKWERTS* has objected. For example in the SHULMAN-VAN WORMER treatment the hydrodynamic force is assumed to act through the centre of the ball whereas with the ball in contact with the wall of the glass tube it is almost certainly off-centre. This means that when the ball is high in the tube it will spin and under these conditions the original SHULMAN-VAN WORMER equation will no longer apply, because the frictional force required to stop the ball from spinning exceeds the limit imposed by the coefficient of friction. Indeed PROF. DANCKWERTS proposes an equation (containing two unknowns) for predicting the onset of spinning.

In reply, SHULMAN acknowledges these objections and also mentions that when the angular position of the ball is great a point will be reached where the ball oscillates, as well as spinning, so that the flow rate cannot be measured accurately. For this reason, in the original work on these instruments, readings were not taken at angles greater than 60 degrees. The correlation in fact is meant to apply only when the ball is at rest and the meters should be designed with the midscale reading at 25-30 degrees.

* *A.I.Ch.E. Journal* 1959, 5, 1, 134.

Fluidising—Experiment and Practice

ONE of the useful properties of fluidised systems is the ease with which streams of solid-gas mixtures can be added or withdrawn from a process, a typical example being the regeneration of catalysts in the catalytic cracking of oils. One method of withdrawing solids from a fluidised bed is to fit an orifice in the wall of the containing vessel. The pressure differential between bed and the outside atmosphere is sufficient to force the gas-solid mixture through from the orifice. Apart from the equations present to express the discharge through such orifices, some important conclusions have been drawn from a recent investigation: its authors, LEOPOLDO MASSIMILLA and co-workers* show that the rate of discharge of solids through an orifice is, for a given material, independent of the flow rate of the fluidising gas (air in the experiments) and depends solely upon the diameter of the orifice and the efflux pressure.

Another addition to the growing list of processes formerly carried out by the fixed method is the full-scale recovery of carbon bisulphide. The particular example is the plant recently erected by Courtaulds at a cost of £500,000 and appropriately dubbed "Landmark" on account of its 170 ft height. It recovers the bisulphide by continuous adsorption upon fluid beds of active carbon followed by steam stripping also carried out fluid-bed-wise in order to remove the absorbed bisulphide.

* "A Study of Streams of Solids Flowing from Solid-Gas Fluidised Beds." Leopoldo Massimilla, Vittoria Betta and Carlo Della Rocca. Paper given to the A.I.Ch.E. 40th National Meeting, May, 1959.

Disposing of Radioactive Waste

PUBLIC and users alike will be glad to know that a complete service for disposing of radioactive waste is potentially available. This service was announced in a paper by A. W. KENNY to the Institute of Public Cleansing. Our relief is tempered a little by the qualification *potentially*, which has an ominous ring suggesting the need for vigilance too. The arrangements can be summarised as follows:

1. About 10 microcuries of beta-gamma-emitting nuclides per refuse bin would not constitute a hazard to refuse-disposal workers and might be disposed of without precaution.
2. After examination of the circumstances, up to 50 microcuries per bin might be allowed.
3. Up to, say, 10 millicuries of carbon – 14, or tritium and similar volatile, innocuous radionuclides can be incinerated.
4. Up to, say, 1 millicurie of material of half-life less than a year and 100 microcuries of longer-lived material could be disposed of at tips provided:
   (*a*) the waste is taken there by the user;
   (*b*) it is buried immediately to a depth of at least 3 ft ; and
   (*c*) the intended use of the land ensures it will not be disturbed for 10 years.
5. After examination of the circumstances, larger amounts of activity might be disposed of at the tip.
6. If disposal through a local authority service cannot be arranged, the Ministry of Housing and Local Government (to whom application should be made) can often make arrangements with A.E.R.E., Harwell, for disposal at sea.

The figures were given as suggestions with no official significance; they are not rigid limits but low values applicable to most wastes. Nevertheless, MR. KENNY is Radiochemical Inspector at the Ministry of Housing and Local Government and his "suggestions" have a corresponding weight and authority. The position is due to be brought under formal legal control according to a written Parliamentary reply of the Minister by the introduction of legislation.

Remotely Actuated Metering Pump

IN a metering pump now in use at U.K. nuclear energy establishments, the actuating mechanism is separated from the metering head which moves the liquid. Drive is transmitted by means of a pulsating column of vacuum oil which can operate a number of heads simultaneously. In the case of the remotely controlled pumps for nuclear applications, an additional component known as a "Regulator" is used to control the metering head displacement. Other versions are directly controlled from the metering head itself. The latter then consists of a stainless steel or P.T.F.E. diaphragm unit—with adjustable volumetric displacement—and a contact head carrying all the parts coming into contact with the pumped medium. The ball type valves used in the contact head are in tandem so that slurry can be handled. On a pressure stroke the metering head diaphragm is displaced to the limit of its travel and a surplus volume of oil is expelled through a relief valve to the oil reservoir. On a suction stroke the diaphragm is displaced to the limit of its travel and then cavitation occurs in the pump cylinder. An inlet valve opens to admit oil to the cylinder and this volume of oil is expelled at the next pressure stroke. In this way it is ensured that the diaphragm moves between fixed limits, which means that delivery is a function of diaphragm positioning and the speed of the oil pump only, and is therefore independent of installation conditions. Actually the metering head has two diaphragms separated by a buffer chamber and it is the adjustable contents of this chamber that determine the stroke. Although water is normally used as the diaphragm buffer liquid, silicone liquid may be used where high temperatures are likely to be encountered. Development was initiated by the Atomic Energy Authority at Harwell, in conjunction with Kontak Limited, for handling highly corrosive, radioactive and toxic materials. Accuracy is claimed to be better than $\pm 2\%$ within specified conditions and $\pm \frac{1}{2}\%$ on repeatability under fixed conditions.

British Chemical Engineering
A HEYWOOD PUBLICATION

Investment for Automation

FEW terms can have suffered such diverse interpretation as automation, a diversity paralleled by the variety of opinions currently held about its eventual benefits. It is not surprising that clarity on this stage in the development of technology should be provided by the efforts of an international body, for this is what the United Nations Economic Committee for Europe have done with their publication on the economic implications of automation.*

Recognising the existence of differing concepts, the committee charged with preparing this report wisely commenced it by proposing a simple working definition of automation. By this term is to be understood not only the mechanisation of productive processes, but also—aspects of greatest interest to chemical engineers—the automatic control and direction of processes including methods relying upon high-speed calculating machines.

Having defined their subject and as a preliminary to presenting their conclusions on its economic facets, the committee take us quickly through the main stages of its development before discussing in some detail its nature and the reasons for its introduction. Many of the reasons outlined are already well recognised by engineers, such as the need to reduce labour costs, the inability to control many processes without automation, and its use to ensure the safety of operators of hazardous processes. It is useful to be reminded, however, that it offers greater plant utilisation and more efficient use of raw materials, and it is here that the report stresses the importance of the more advanced forms of automation based upon computer mechanisms. This is appropriate in view of the current interest in optimising chemical processes by means of these systems, exemplified by recent symposia, such as the one organised earlier this year by the Institution of Chemical Engineers in conjunction with other bodies.† From these meetings several approaches leading to the achievement of this advanced type of automation were apparent. However, these methods are still in their infancy, and it is unlikely that the case histories given in this report refer to such advanced techniques. It would be useful if a further report outlining some of the methods employed in their examples could be prepared. As some of these included a sulphuric acid from pyrites plant and a platformer plant, this would be a valuable service. As for the consequences of automation, no firm conclusions on its economic benefits in particular industries could be made, despite the many noteworthy advantages which the report is able to quote. This is partly due to the fact that the cases for each particular industry before the committee did not constitute representative samples, and also because information on the effect of automation on costs was, in many cases, lacking.

Since it is clear that this important means of achieving higher productivity cannot expand without considerable expenditure, the problems of investment in automation are examined very closely. The view that its introduction must invariably be accompanied by heavy expenditure is considered an exaggeration, as examples can be quoted where the reverse has been found to hold. It is, of course, true that if the outcome of installing automation equipment is predominantly a reduction in labour, then the capital costs become more important, and this factor may place a restraint upon the wider use of automation. However, the major question governing the expansion of automation lies in the ability to invest.

In this country, judging from the latest Cohen report, the money market is in a healthy state, and there are plentiful signs from industry which betoken a willingness to invest, especially in the field of chemicals and petrochemicals. It is more likely that the obstacles to more automation are much more artificial.

As Sir Alexander Fleck pointed out in his recent Dunn Memorial lecture, a sizeable part of British industry has been living upon its accumulated technological capital without replenishing its reserves through research and the adoption of new processes. To this retarding influence, which may at last be on the wane, must be added the traditional ignorance of the scientific and the technical technological matters which still imprisons some of our leaders of industry. The obscurity of presentation which still bedevils many of the authorities in the field of automation is a lesser obstacle, but one which nevertheless makes it difficult for the less enlightened to orientate themselves properly towards it and so be in a position to take decisions.

What has to be faced is that the widespread use of automation is certain to require investment in other directions. There can be little doubt that the *per capita* consumption of electrical power will increase greatly, and this will demand greater generating capacity. To meet the demands for the skilled personnel required for the development of automated industries, educational resources will also have to expand and many new courses be initiated. The unautomated industries and the industries with but a modicum of automation may also need to enlarge in order to absorb the labour force released from the more advanced industries. To deal with such problems effectively requires a national investment policy based on long-term aims rather than on short-term profitability.

* "The Economic Implications of Automation in Europe". The United Nations Economic Commission for Europe. Geneva, 1959.

† Joint Symposium on Instrumentation and Computation in Process Development and Plant Design, May 11-13, 1959. Organised jointly by the Institution of Chemical Engineers and the Society of Instrument Technology and the British Computer Society.

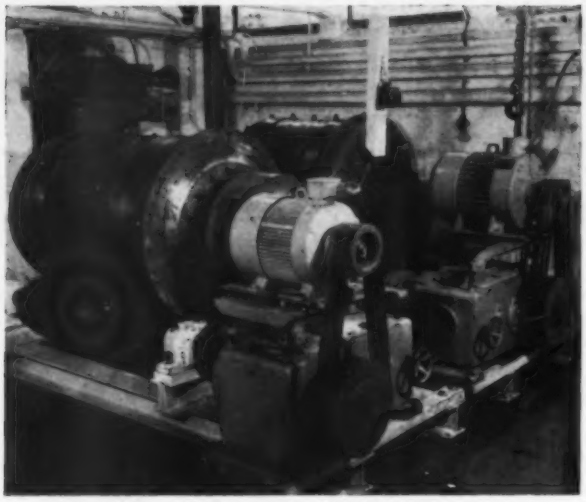


Fig. 1. Mills for supercritical grinding experiments in the Mineral Dressing Laboratory of the State Institute for Technical Research, Helsinki.

621.926.5

GRINDING AT SUPERCRITICAL SPEEDS

A neglected method of obtaining greater mill capacity in which the material to be ground is also the grinding medium

by Prof. R. T. HUKKI, Sc.D., M.A.I.M.E.

THE purpose of this paper is to present in a condensed form some of the results obtained so far in practical and theoretical investigations of the fundamentals of grinding at supercritical speeds. The laboratory and pilot-plant experiments have been carried out in the Mineral Dressing Laboratory of the State Institute for Technical Research, Helsinki, Finland. Earlier work in this field has been already described.[1–8]

The critical speed of tumbling mills is usually given in the following form:

$$n_c = 76.63 \frac{1}{\sqrt{D}} \text{ rpm},$$

where D is the inside diameter of the mill in ft.

It should be noticed that no factor indicating the coefficient of friction between the mill lining and the tumbling load is included in the above equation. If this factor = 1.0, the formula holds as such, and grinding is possible at subcritical speeds only. Such a condition can be obtained, e.g., by providing the mill with heavily ribbed lining such as that often used in conventional practice. If the coefficient of friction is <1.0, the speed at which the tumbling load will centrifuge will be greater than the speed indicated by the formula. Slippage will now take place between the mill lining and the outer layer of tumbling medium. As a result, grinding at supercritical speeds becomes possible.

Determining Mill Characteristics

The most important single experimental discovery was the observation that the so far unknown, yet very important mill characteristics could be determined by using tumbling medium alone in the mill without any material to be ground. In this way the power consumption was determined: (a) for motor and speed regulator alone; (b) for the drive with an empty mill; and (c) for the drive and mill loaded with various loads of medium and all as a function of mill speed. Fig. 3 shows a series of such ball-mill characteristics obtained in a 3 × 3 ft pilot-plant mill equipped with a smooth lining.

The pilot-plant ball mill shown in Fig. 1 has been operated at speeds up to 230% and, in one series, up to 313% of the theoretical critical speed range. To study the unknown speed range beyond these figures, a smaller mill was constructed and operated at speeds up to 2000% of critical, representing an actual speed of about 1550 rpm.

On the basis of the mill characteristics obtained experimentally and of a mathematical analysis of the mill dynamics, it has been found that the mill speed may be increased if:

(a) the total mass of grinding medium decreases;
(b) mass of the individual grinding piece increases; and
(c) the coefficient of friction between the outer layer of the medium and the mill-lining decreases.

Grinding at Subcritical and Supercritical Speeds

Fig. 2 shows the difference between the operating principles of tumbling mills at subcritical and at supercritical speeds. Case A represents typical conventional practice. The mill lining and the outer layer of medium opposite to it proceed in the same direction at equal speed. Grinding takes place primarily at the toe of the charge by virtue of cataracting, cascading or tumbling effects with some action within the medium itself. Very little grinding will take place between the medium and the lining.

Case B represents grinding at supercritical speeds. In addition to the grinding actions already explained, there is now a very effective attrition zone between the mill lining (the "bucking board") and the outer layer of the medium (the lower surface of the "muller"). The "muller" is pulled at high speed in respect to the "bucking board". At high speeds the speed difference becomes great; even enormous. At the same time, the thickness of the layer of material that must be ground to produce conventional tonnages will be reduced to unbelievably small figures, to a fraction of one millimetre.

It has been found that by proper selection of the basic variables, a wide supercritical speed range becomes available for grinding. In what follows, the fundamental conditions for grinding of coarse material and fine material will be analysed.

R. T. Hukki *is Professor of Mineral Dressing, Finland Institute of Technology, Helsinki, Finland.*

Coarse Grinding at Supercritical Speeds

Grinding of coarse material in a tumbling mill must be based on blows affected by freely falling bodies. In order to obtain a heavy blow, the momentum of the falling body must be great. Fig. 4 shows the relationship between the linear momentum expressed in kg cm/sec. of various grinding media in function of mill diameter. The momentum is obtained by multiplying the mass of the body (in kg) by its speed in cm/sec. As can be seen from Fig 2, a rod mill is a good coarse grinding mill because the momentum of the rod is high. It can be also seen that the momentum of large pieces of ore or rock can equal that of the metallic rods if the lumps are of sufficient initial size and if they have a sufficient free fall. The operation of the Aerofall mill is correctly based on these same facts. However, to obtain the sufficient free fall at subcritical speeds, the Aerofall mill must be constructed short enough to provide the necessary friction to elevate the lumps sufficiently high. A longer mill operated under otherwise similar conditions would not work because of the slippage of the tumbling load. However, if the mill is speeded up to the supercritical range, the speed will counteract the slippage and the medium will be raised again to a sufficient height to provide the free fall necessary. At the same time a shear zone will be formed between the mill lining and the outer layer of the charge.

In conventional rod mills, the higher momentum of the rod is obtained by preventing slippage by heavy lifter bars placed on the lining. If the rod mill is equipped with a relatively smooth lining, the speed can be increased up to the supercritical range. The grinding capacity of the mill will be simultaneously increased. Rod wear and liner wear will also increase at the same time, perhaps at a rate higher than the capacity; thus such a practice may not be always economically attractive. On the other hand, if the rods are replaced by an autogenous medium, the economics of the supercritical coarse grinding should be sound. Moreover, autogenous lining also becomes a possibility because of the supercritical speed. The shear zone will now be formed between an attached layer and a movable layer of the charge.

The autogenous coarse grinding mill operated at supercritical speed can take over the functions of the conventional rod mill operated with metallic medium within the subcritical speed range. As pointed out earlier, coarse grinding must be based on impact. The major variables that affect the momentum of the impacting bodies are the mass of the body, the diameter of the mill, and the supercritical speed of the mill. The maximum size of the material to be ground must be selected to suit the momentum available in the grinding unit. The proper speed range for the grinding of coarse material will be the low supercritical speeds, perhaps from 100% up to 150% of the critical.

Fine Grinding at Supercritical Speeds

Fine grinding, if performed effectively, must be based on attrition, not on impact. In tumbling mills, effective attrition grinding can be obtained at supercritical and only at supercritical speeds. In grinding, fairly finely divided materials, such as rod mill discharge still finer, the grinding conditions must be selected in such a way that the attrition effect will be at its optimum.

In conventional fine grinding, small steel balls, other shapes of metallic medium, flint pebbles, or autogenous crushed ore pebbles are used. In mills where low-gravity medium is used, the grinding capacity is lower than in mills operating with metallic medium. In Fig. 5 the relative mill capacity is shown as a function of the effective specific gravity of the medium. By effective specific gravity is meant the true specific gravity of the medium corrected for the buoyant effect of the pulp or of the semi-fluid bed of solids within the mill. In grate mills, or in peripheral discharge mills, the effective specific gravity of the medium is always higher than in overflow-type mills. If a reference capacity of 10 t/h is given for an overflow mill grinding with steel balls (specific gravity 7.8) ore of specific gravity 3.0 at a pulp density of 70% solids (specific gravity 1.87), an autogenous mill using pebbles of this same ore would grind only 1.9 t/h, while a mill operating with tungsten carbide balls would grind 19.0 t/h under otherwise similar conditions. The grate-type mills of the same effective size would have maximum capacities of 5.06, 13.2 and 22.1 t/h with ore pebbles, steel balls and tungsten carbide balls respectively as shown by Fig. 4. This assumes that the material to be ground would have no buoyant influence on the medium at all.

It should be noted that the statement that a grate-type mill has a capacity about 30% higher than the respective overflow-type mill operating with steel medium is borne out with the above case. The percentage difference between the two figures is, however, very much more pronounced with ore pebbles, the difference being here 160%. This example shows clearly that in all attempts to use a low-gravity medium with a high degree of efficiency, the mill should be of the low-discharge type.

It is a general belief that within the narrow subcritical speed range of conventional practice, the mill capacity is directly proportional to its speed. At Outokumpu, Finland,[4] large-scale, autogenous fine grinding tests have shown that within a speed range 57.6 to 104% of the critical the tonnage of new −65 mesh material produced increased as a

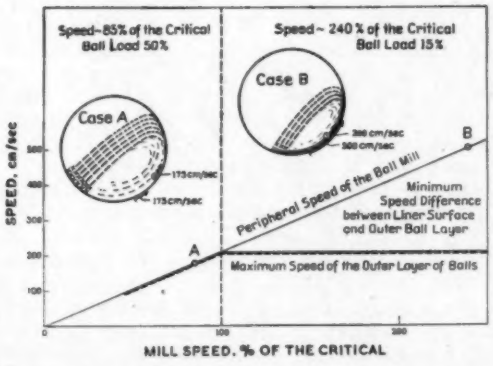


Fig. 2. A comparison between grinding actions of mills operated at subcritical and supercritical speeds.

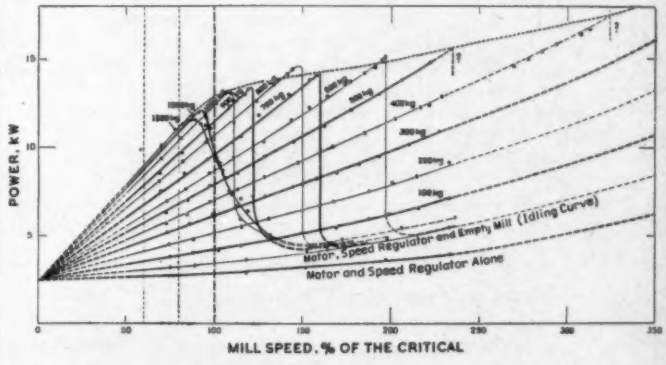


Fig. 3. Pilot-plant ball mill characteristics without feed. The mill is equipped with a smooth lining.

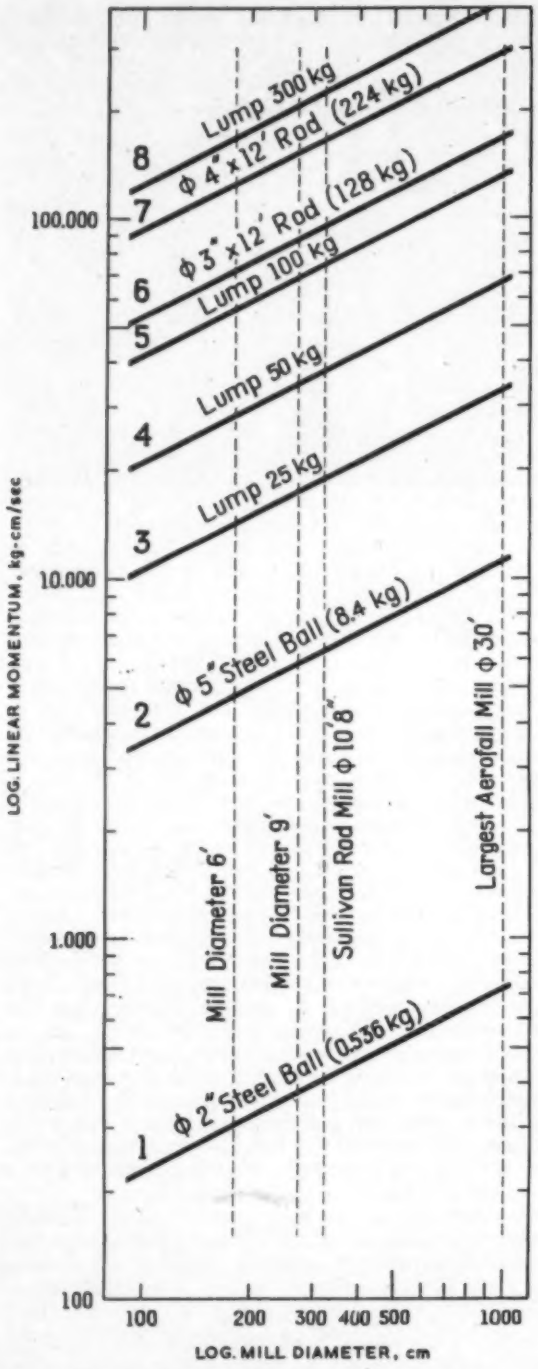


Fig. 4. The relationship between the linear momentum of different falling bodies and the mill diameter.

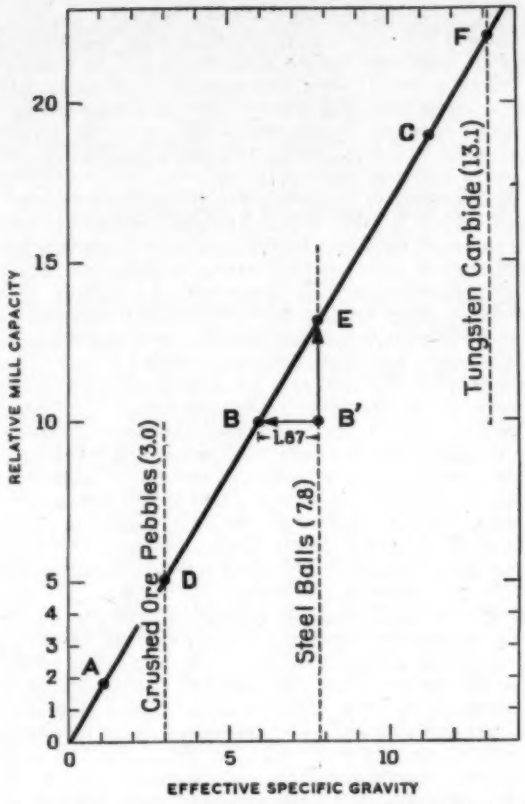


Fig. 5. The relationship between mill capacity and effective specific gravity of grinding media.

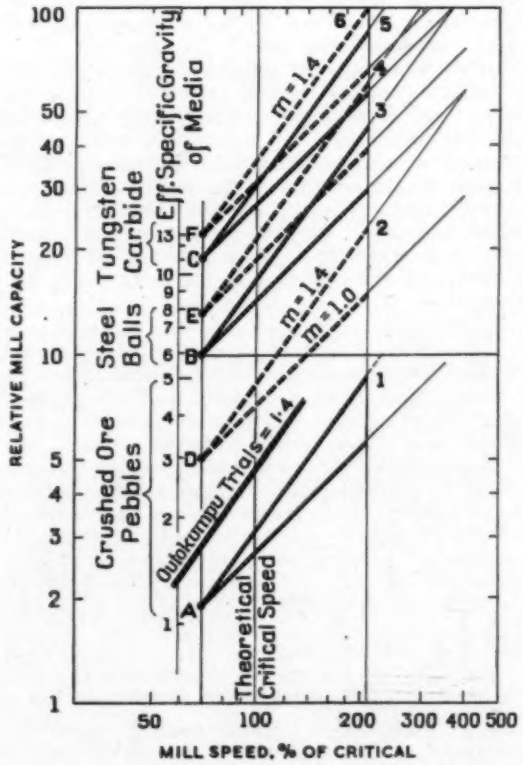


Fig. 6. The relationship between mill capacity and mill speed shown on logarithmic paper. The solid lines indicate overflow-type mills, the dashed lines grate-type mills.

power function of the speed, the exponent being 1.4. This is shown in Fig. 6. On a logarithmic paper, the capacity-speed relationship is represented by a straight line of slope $m = 1.4$.

Points A, B, C, D, E and F in Fig. 5 have been redrawn in Fig. 6 in such a way that the speed of all these mills is assumed to be 70% of the critical. Through each point two lines are now drawn, one at $m = 1.0$, the other at $m = 1.4$. These lines represent capacity-speed relationship in accordance with the two conceptions explained in the preceding paragraph.

As shown, an increase of the mill speed from 70% to 210%, a 3-fold figure, would indicate an increase of the mill capacities either 3- or 4.6-fold. This would depend on the exponent and the condition that the increase would continue at the same rate within the supercritical speed range as has been observed at lower speeds.

Naturally it was now of particular interest to test at what rate and how far the fine grinding capacity would increase at supercritical speed. Feed to the process was prepared in a pilot-plant rod mill. About 1 t/h was treated at 70% of the critical, exponentially ($m = 1.4$) increased tonnages at higher speeds. The rod mill product was ground in the pilot-plant ball mill operating in a closed circuit with a mechanical classifier. With steel-ball medium, tests could be carried out at speeds from 70% up to 140% of the critical. These tests indicated that the fine grinding capacity followed roughly the Outokumpu relationship. At greater speeds, the auxiliary equipment available in our laboratory could not handle the large volume of pulp, and further tests had to be discontinued. Thus we were not able to determine the maximum fine grinding capacity of the pilot-plant ball mill. It should be obvious, however, that for a certain job a maximum must exist for a certain mill. No knowledge of this limit exists at present. New tests are now under way to clarify this question.

A study of Fig. 6 indicates further that it might be possible to remove steel balls from an overflow-type mill, to replace them with autogenous medium, and to recover the former capacity partly, fully and even more than fully by speeding the mill to supercritical range. The results of such a test should be of particular interest. For a comparison, a continuous fine grinding experiment was first performed at a speed of 70% with steel balls. The steel medium was then replaced by limestone pebbles and the mill was speeded up to 230% of the critical. Because the specific gravity of limestone was only 2.8, it was estimated that the capacity with pebbles should be about 94% of that obtained with steel balls, assuming that the Outokumpu exponent would hold. The new −65 mesh material produced was actually 91.8% instead of 94%.

This result is of great potential importance, especially in all cases where a change from steel medium to autogenous, crushed-ore-pebble medium is considered. CROCKER[5] in Canada has recently made a statement that in nine cases out of ten, ore itself can be used more effectively and far more economically than steel balls to do the grinding job. This statement is fully justified, yet surprisingly little appreciated. However, it also follows that to do the job with ore pebbles as recommended by CROCKER, the number of mills must be at least doubled, or their size enlarged in order to get the same capacity.

As shown in Fig. 6, the reference capacity of 10 t/h, corresponding to the capacity of an overflow-type ball mill operating at 70% of the critical, can be equalled by a grate-type pebble mill of the same effective size at a speed of 115-140%, or by the same overflow mill charged with pebbles at or above 230%. With increasing specific gravity of the ore pebbles, the corresponding speeds can be reduced. It is therefore possible that a change from the steel to the autogenous medium can be effected without a change in mill capacity. This test also indicates that in order to get the full benefit of low-gravity autogenous medium in fine grinding, the mills should be operated at supercritical speeds. Moreover, the Outokumpu test has also shown that the energy consumption stays at a constant value for the entire speed range from 57.6 to 104%. Both the mill capacity and the power consumption increased at the same rate. Energy consumption with crushed ore pebbles was about 1 kWh/t higher than with steel medium. This increase results from the fact that the idling power has to be divided in this case between a smaller tonnage in pebble grinding than in steel-ball grinding.

Wear of grinding medium and of mill lining will naturally be greater at supercritical speeds that at subcritical speeds. If the balls are replaced by crushed ore pebbles, the increased wear of the medium will result in additional tonnage of the final product, a favourable rather than an unfavourable feature. Regarding the mill lining, the old mineralogical rule that a harder mineral will scratch the softer one may be successfully applied to some extent. At Outokumpu, the low supercritical speed of 104% has caused no excessive wear. In extreme cases, however, a compromise should be made between mill speed and type of the metallic or autogenous lining.

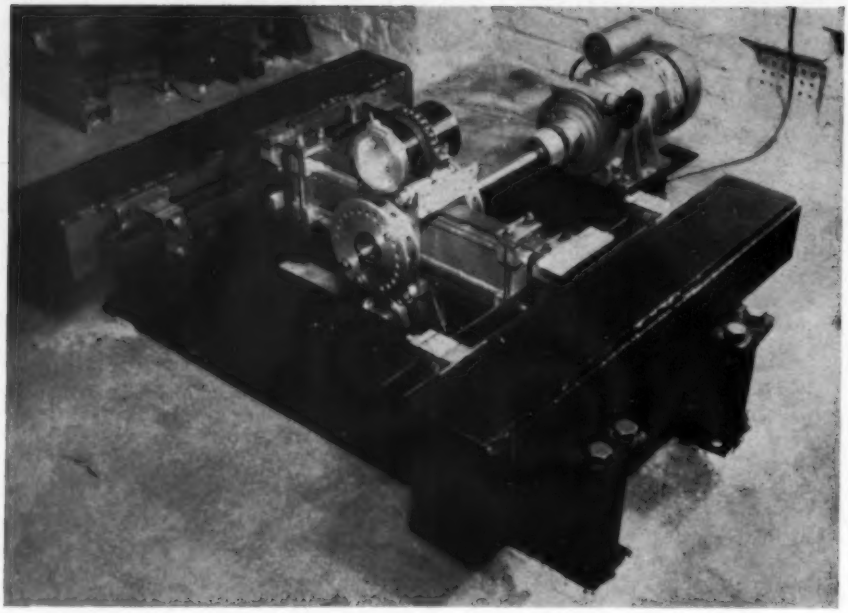
To date, about 300 tons of different materials have been ground at supercritical speeds up to 230% in our pilot-plant mills. No material has so far been found that did not respond favourably to the process. At Outokumpu more than a milion tons of siliceous copper ore have been autogenously ground at a low supercritical speed. Tremendous savings have been indicated compared with the former practice with steel balls at subcritical speeds.[4] Extensive tests on an industrial scale are now being carried out at higher supercritical speeds; at least up to 200%. While it is yet too early to predict what speeds will be the most advantageous for what purpose, it can, however, be stated that the wheels of industrial grinding have already started to operate at supercritical speed and cannot be stopped.

Certain new features of construction will be necessary in plants using supercritical speeds. The most important single item is the fact that the feed and medium to the mill must be introduced by gravity, not by means of a scoop. As a result, the mechanical classifier as conventionally applied will lose its transporting function. Thereafter the shape of the classifier becomes of little importance. Should grinding at supercritical speed find a wide use in the future, the related sizing operation is also bound to get new features.

Grinding at supercritical speed has been known for more than 50 years, but, despite this, subcritical speeds are universally used. The recent investigations have revealed that the operation of tumbling mills is, after all, based on certain simple fundamental physical laws and principles. The author expects that within a rather short time a wealth of new knowledge will be available regarding the basic characteristics of grinding. It will be found that the conventional practice will fit into the same overall picture, but will cover only a narrow area at the subcritical speed range. Once the fundamental principles are available, the present chaotic concepts of applications can be reduced to simple and logical solutions.

REFERENCES

[1] Hukki, R. T. "Grinding at Supercritical Speeds in Rod and Ball Mills", *Prog. in Mineral Dressing*, Stockholm, 1958, 85-122.
[2] Hukki, R. T. "Fine Grinding at Supercritical Speed", *Mining Eng.*, May, 1958, 581-91.
[3] Hukki, R. T. "All-autogenous Grinding at Supercritical Speeds", *Mine & Quarry Eng.*, July, 1958, 304-11.
[4] Tanner, H., and Heikkinen, T. "Crushing and Grinding at Outokumpu", *Prog. in Mineral Dressing*, Stockholm, 1958, 123-38.
[5] Crocker, B. S., *Northern Miner*, November, 1958.



621.926.9

Fig. 1. A view of the vibratory ball mill used for the investigations.

AN EXPERIMENTAL INVESTIGATION OF VIBRATION MILLING

Results obtained with an experimental mill suggest the conditions necessary for the effective use of this technique

by H. E. ROSE, D.Sc. (Eng.), Ph.D., M.I.Mech.E., M.I.C.E.,* and R. M. E. SULLIVAN, B.Sc. (Eng.)†

THE preparation by grinding of very fine powders is a problem of great industrial importance and, since the production of such materials in a conventional ball mill is a lengthy process, the search for improved methods of treatment is being continuously prosecuted by many workers. In the course of this search the vibration mill has received some attention but, strangely enough, in spite of the possibilities for rapid grinding which this type of mill appears to offer, the general behaviour of the machine has not received comprehensive systematic investigation. For this reason a research mill, in which all the relevant parameters are capable of independent adjustment, has been designed, and an extensive investigation of the influence of the different variables has been carried out.

The Research Mill

The research mill (see Fig. 1) consists of a central "unit", to which are bolted a pair of mill bodies of any desired shape. This unit, which is in fact a complex structure, is mounted at the mid-point of a pair of leaf springs which allow vertical motion. By means of a pair of clamps, which lock the springs on to a duralumin girder at selected points, the effective length, and so the strength, of the springs may be adjusted. The ends of the springs are clamped to blocks, which form the ends of the duralumin girder, and the blocks are, in turn, bolted to the mid-points of two other pairs of springs, these springs allowing motion in the horizontal direction.

The ends of these two pairs of springs are themselves clamped to blocks which are attached to the main frame of the mill. These four blocks, which are in the nature of clamps, may be adjusted for position and so allow variation of the effective length and thus the spring strength of these springs. Thus the spring strengths for the horizontal and the vertical motion may be independently varied. This system of mounting is covered by British Patent Application No. 2365/59.

The complex central unit carries a horizontal shaft which rotates in roller bearings and carries a pair of adjustable balance weights. Each of these balance weights consists of a pair of discs, keyed to the shaft, between which is sandwiched a fixed balance weight and a second weight, the angular position of which, relative to the first, may be adjusted. Thus, when the weights are set at 180 degrees, there is no unbalanced force induced by the rotation of the disc; when the weights are brought together the out-

* **Dr. Rose** *is University Reader in Mechanical Engineering, King's College, London.*
† **Mr. Sullivan** *is research student, King"s College, London.*

Symbols Used

A = a parameter;
b = diameter of the particle or surface mean diameter of the powder sample;
d = diameter of the balls;
D = diameter of the mill body;
e = base of natural logarithms;
g = acceleration due to gravity;
H = the energy required to bring about unit change of surface of the material undergoing grinding;
J = mill filling of grinding media $\left(\frac{\text{Vol. of balls} + \text{Vol. of space between balls}}{\text{Vol. of Mill}}\right)$;
K = a constant;
n = a parameter;
S = specific surface on weight basis (cm^2/gm);
S_v = specific surface on volume basis (cm^2/cm^3);
R = rate of production of specific surface on weight basis (L^2/MT);
R_V = rate of production of specific surface on a volume basis ($1/LT$);
U = mill filling of powder $\left(\frac{\text{Vol. of particles} + \text{Vol. of space between particles}}{\text{Vol. of space between balls}}\right)$;
Z = a parameter;
α = effective amplitude of mill vibration;
β = amplitude of vibration in the horizontal direction;
γ = amplitude of vibration in the vertical direction;
δ = density of the powder;
ρ = density of the grinding media; and
ω = angular velocity of the vibration ($2\pi \times$ rps).

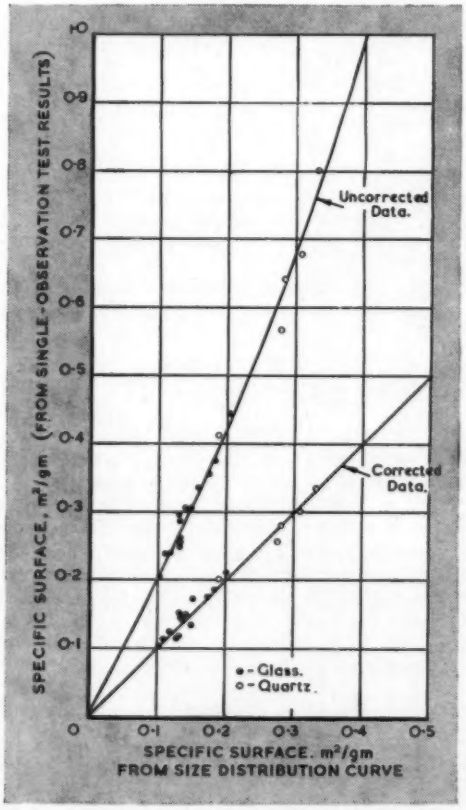


Fig. 2. Graph showing estimations of specific surface for a sub-sieve sample.

of-balance force is a maximum.

The shaft is rotated, through a cardan shaft fitted with flexible rubber couplings, by an electric motor fitted with a Kopp speed variator and, therefore, a stepless speed variation, between about 400 and 4000 rpm, is obtained. By the correct adjustment of the position of the clamps, any desired amplitude in the horizontal and in the vertical direction can be obtained at any specified frequency.

Measurement of the Rate of Milling

The question of the basis upon which the progress of the milling process is to be expressed is a matter for some debate. Clearly, if the size distribution curves for the different products are similar, then any basis, such as the mean particle size, the mode particle size or the specific surface of the product, may be used; the different bases giving results which differ only by a multiplicative constant.

In practice, however, the size frequency curves are not geometrically similar, so the different bases are not strictly comparable. For this reason the authors have taken the view that the real function of a mill is to produce new surface in the product and so the change of specific surface of the product can be said to be a real criterion of the rate of grinding.

On this basis the tests were carried out as follows: A selected feed material, normally quartz sand sized between about 150 and 500 microns, or between about 500 and 850 microns, is milled under the required conditions of frequency, amplitude, etc., for the desired time, say 30 minutes.

At the end of this period the material is withdrawn from the mill and an accurate sample drawn by careful repeated "quartering". This sample is then analysed for size by the use of a set of seven "Endacott" 2-in. diameter tests sieves, the procedure being to sieve for 15 minutes on a "Rotap" machine, fitted with an adaptor to carry the small sieves. By this means the size distribution of the material having a size greater than about 50 microns is obtained. The size distribution of the material of size less than this figure is obtained by use of an "Eel" photo-extinction sedimentometer. From these size distribution curves, the specific surface is calculated, on the assumption that the particles are spherical, and the specific surface of the product is then calculated from the two sets of data obtained.

The determination of the size frequency curve for the sub-sieve material is a lengthy process, taking several hours per sample so the process was shortened by the adoption of a "single-observation" photo-extinction test, the results being adjusted by use of a semi-empirical correction factor deduced by ROSE.[1] By this means the time for the estimation of the specific surface of the sub-sieve sample was reduced to about half an hour.

In Fig. 2 are shown the "uncorrected" and "corrected" single observation results, plotted against the specific surface as determined from the size frequency curves, for a number of tests and it is seen that the "corrected" results give the specific surface with an accuracy sufficient for the present purpose. The total specific surface, determined in this way, for a number of milling times are then plotted against the time, and curves, of which those of Fig. 3 are typical, are obtained.

If now a horizontal line is drawn across this curve and the slopes of the test curves, at the points of intersection, determined, these slopes give the rate of grinding R ($cm^2/gm/hour$) for the specified conditions and for a known mean particle diameter. The rates of milling, deduced in this way, form the basis of the subsequent analysis.

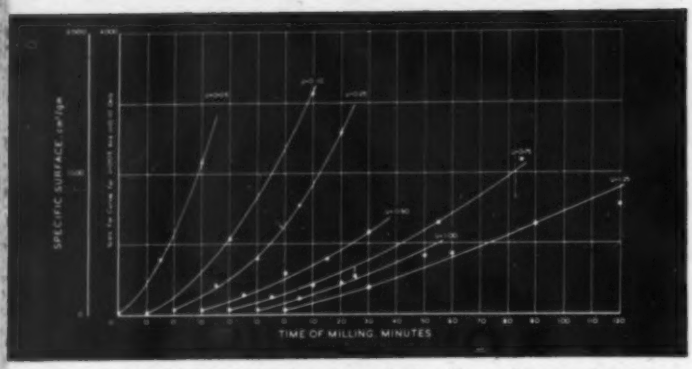


Fig. 3. Typical plot of total specific surface against time of milling for different amounts of mill charge.

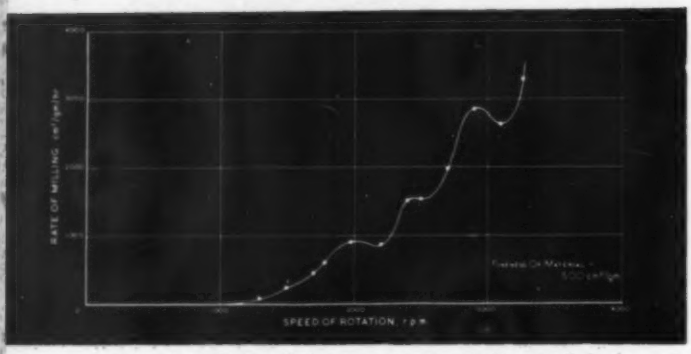


Fig. 4. Relation between rate of grinding and frequency of mill oscillation.

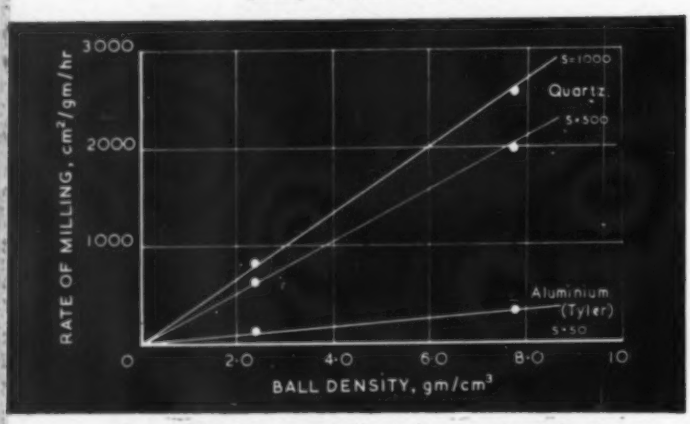


Fig. 5. Effect upon rate of grinding, produced by the use of grinding media of different densities.

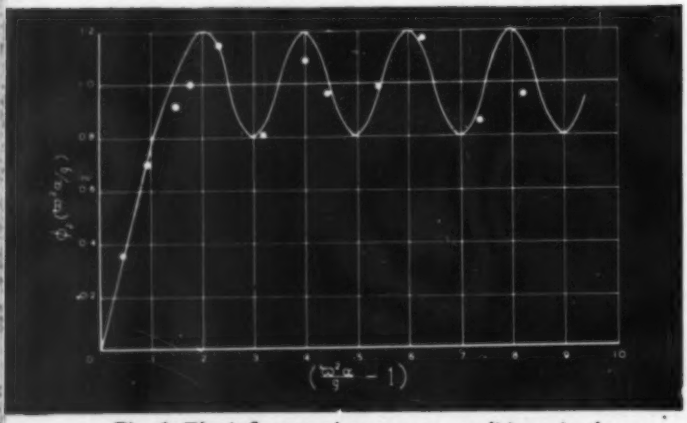


Fig. 6. The influence of resonance conditions, in the mill, on the rate of grinding.

Theoretical Analysis

It appears reasonable to believe that, in a vibration mill, the time rate of production of specific surface R_V (on a volume basis), would depend upon the frequency, ω, of the vibration, upon the diameter of the ball d, upon the diameter of the particle b, upon the density of the ball material ρ, upon the volume of the balls in the mill J, and upon the volume of the powder in the mill U. The rate of grinding would also be expected to depend upon the size D of the mill body, since the length of the column of grinding media undergoing acceleration, and so the contact pressures, would depend on this quantity.

The rate of grinding would also be expected to depend upon the horizontal and vertical amplitudes of the vibration, β and γ respectively and upon the acceleration due to gravity g. The latter quantity enters the problem because, for a given vertical acceleration $\omega^2\gamma$, the contact pressure when the mill body commences to move upwards will be proportional to $(\omega^2\gamma + g)$ and, when it commences to move downwards, to $(\omega^2\gamma - g)$, and so the rate of grinding will depend, to some extent, upon the gravitational field.

From the practical point of view, the use of the component amplitudes, β and γ, complicate matters in that an extra group is introduced. For this reason it is convenient to introduce the effective amplitude, α, and to determine a relationship, possibly empirical, between this variable and the component amplitudes.

Finally, the rate of grinding will depend upon the grinding characteristics of the material undergoing treatment; that is, for example, upon H, the energy required to bring about unit change of product surface. These relationships can then be written symbolically as:

$$R_V = \varphi\{\omega^{x_1}, d^{x_2}, b^{x_3}, \rho^{x_4}, D^{x_5}, \alpha^{x_6}, g^{x_7}, H^{x_8}, J, U\} \quad \ldots . (1$$

where φ denotes "some function of each of the following variables". Application of the well-known principles of dimensional analysis then leads to the following equation:

$$\left(\frac{R_V \alpha}{\omega}\right) = \varphi\left\{\left(\frac{\omega^2 \rho \alpha^2}{H}\right), \left(\frac{\omega^2 \alpha}{g}\right), (d/\alpha), (b/\alpha), (D/\alpha), J, U\right\} \quad \ldots . (2)$$

Theory places no restriction upon the forms of the functions on the R.H.S. of the equation, but it is convenient, in practice, if they can be cast into the form of a product.

If, as is usually the case, this can be done and if the specific surface is expressed on a weight basis, Equation (2) becomes:

$$\left(\frac{R\delta\alpha}{\omega}\right) = \varphi_1\left(\frac{\omega^2 \rho \alpha^2}{H}\right) \times \varphi_2\left(\frac{\omega^2 \alpha}{g}\right) \times \varphi_3(d/\alpha) \times \varphi_4(b/\alpha) \times \varphi_5(D/\alpha) \times \varphi_6(J) \times \varphi_7(U) \quad \ldots . (3)$$

where δ is the density of the powder and R is the rate of production of specific surface on a weight basis.

In this work dimensionless quantities are, in general, enclosed with round brackets; thus (d/α). Sometimes, however, a dimensionless quantity represented by a single letter is not so enclosed; this, however, may be done when it is desired to draw attention to the dimensionless nature of the variable.

If a different criterion for comminution were taken, for example the limiting stress, σ, a different group is obtained to replace $\left(\frac{\omega^2 \rho \alpha^2}{H}\right)$, in this case $\left(\frac{\omega^2 \rho \alpha^2}{\sigma}\right)$. The forms of the functions φ_2, φ_3, φ_4, φ_5, φ_6 and φ_7 are probably uninfluenced by the criterion of comminution, and so are common to all equations.

It is interesting to notice that the different algebraic forms of these equations should allow the experimental

determination of the fundamental criterion for comminution; that is whether the comminution depends upon the limiting stress, σ, the "Rittinger's constant", H, or whatever the relevant quantity may be.

At the present time the work is not sufficiently advanced to allow this decision as to the true criterion for comminution to be made, but a study of the problem, from this point of view, is in progress.

It is now necessary to study the relationships between the group on the left-hand side of these equations and those on the right, the groups being treated as the variables.

The Influence of the Frequency of the Vibration

The frequency of the oscillation of the mill is, from the point of view of the rate of grinding, probably the most important of the mill parameters. Strangely enough, however, this important variable appears to have received very little study.

In Fig. 4 is shown a curve relating the rate of grinding, R, to the frequency of oscillation of the mill. It is at once seen that at speeds below about 1000 rpm the rate of grinding is negligible, but for speeds greater than this value the rate of grinding increases rapidly with increasing speed. A further noticeable feature is that this curve does not increase steadily, but exhibits a series of maxima and minima.

Examination of Equation (3) shows that the frequency enters two of the independent variable groups and for complete analysis these groups require separate consideration.

The Group $(\omega^2\rho\alpha^3/H)$

The curve of Fig. 5 shows the rate of grinding, R, produced by the use of grinding media of different densities, all other variables being maintained constant; these data are by TYLER[2] and by the present workers. It is at once seen that the relationship is linear, from which it follows that:

$$(R\delta\alpha/\omega)=K(\omega^2\rho\,\alpha^3/H) \qquad \ldots.(4)$$

where K is a constant.

The Group $(\omega^2\alpha/g)$

From Equations (3) and (4) it follows that:

$$(R\delta\alpha/\omega) \div (\omega^2\rho\,\alpha^3/H) = K_1 \times \varphi_2(\omega^2\alpha/g) \qquad \ldots.(5)$$

or, since all quantities other than the speed. ω, are constant

$$R/\omega^3 = K_2 \times \varphi_2(\omega^2\alpha/g) \qquad \ldots.(5a)$$

A plot of R/ω^3 against $\left(\frac{\omega^2\alpha}{g}-1\right)$ is shown in Fig. 6 and a peculiar periodicity is observed.

The explanation of this curve is as follows:

As already remarked, for speeds less than about 1000 rpm there is negligible grinding. This speed, however, corresponds roughly to $(\omega^2\alpha/g) = 1.3$. For $(\omega^2\alpha/g)$ less than unity, however, the mill charge is carried back and forth in contact with the mill shell and the grinding is negligible; a result in accord with the previous observation. Thus, the rate of grinding is a function of $(\omega^2\alpha - g)$, the excess of the acceleration of the mill shell over gravity, and this leads to the use of the group $\left(\frac{\omega^2\alpha}{g}-1\right)$ as the independent variable.

The rate of milling increases roughly linearly for $0 < \left(\frac{\omega^2\alpha}{g}-1\right) < 2.0$; after which the function oscillates sinusoidally between about 120% and 80% with a period of 2.0. This effect arises because, according to the frequency of the oscillation of the mill, the charge, after

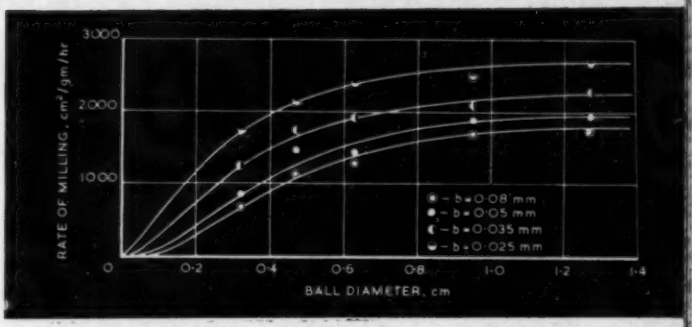


Fig. 7. Effect of ball size upon rate of production of specific surface (weight basis).

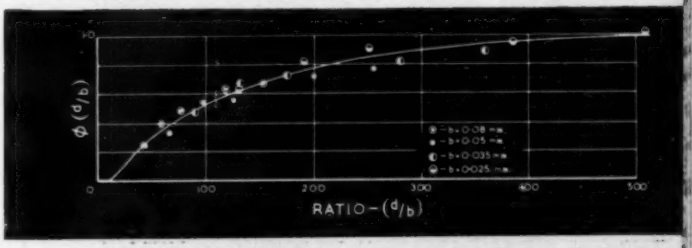


Fig. 8. Relation between rates of milling and the ratio ball diameter to particle diameter.

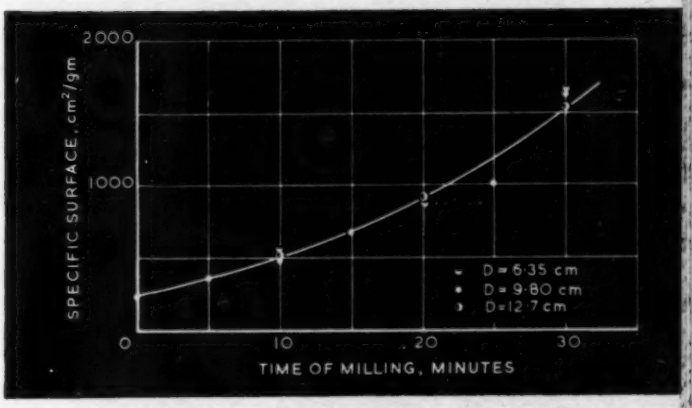


Fig. 9. Relation of specific surface to time of milling for different mill diameters.

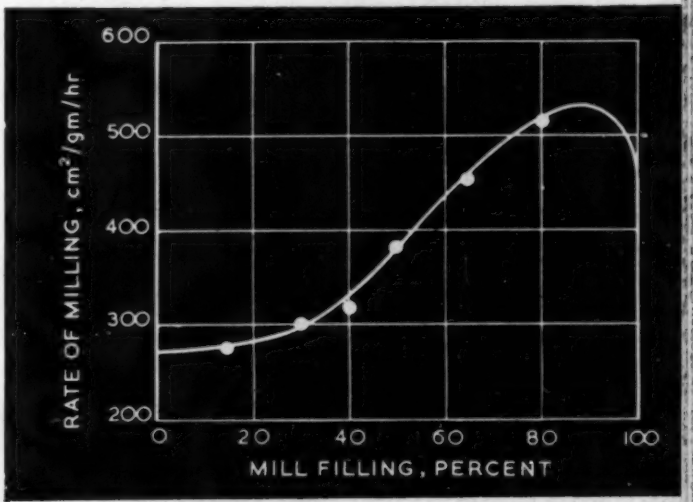


Fig. 10. Rate of production of specific surface for various values of mill filling.

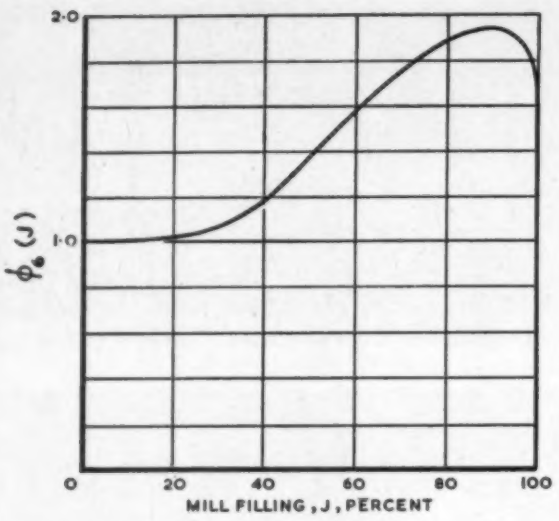


Fig. 11. Relation between volume of mill filling of grinding medium and function of mill filling φ_6(J).

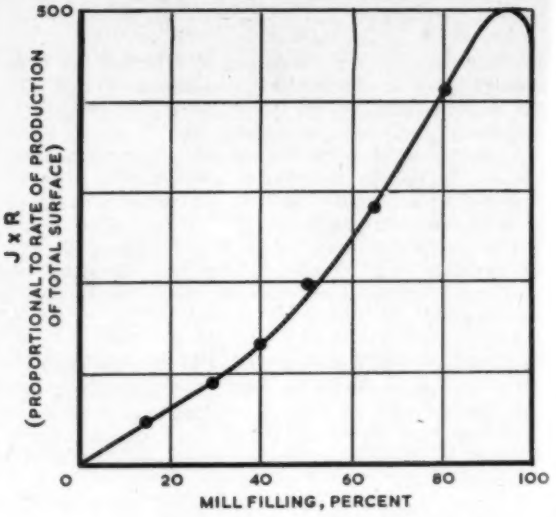


Fig. 12. Effect of mill filling upon rate of production of total surface.

projection upwards, again makes contact with the mill shell as the latter is either:

(1) descending during the same cycle;
(2) stationary at the end of this cycle; or
(3) ascending at the beginning of the next cycle

and, according to the condition, the milling effect will vary considerably.

Furthermore, as the speed is increased, the mill shell will make two, three or more oscillations whilst the charge is "in flight" and so a complicated resonance pattern can be built up. That this is a likely explanation is supported by the observation that the mill emits distinctive noises at speeds corresponding to the various maxima and minima of the curve of Fig. 6. Thus, the curve of Fig. 6 represents the function $\varphi_2(\omega^2\alpha/g)$.

Further work is required to establish whether this curve is modified appreciably at different values of the mill filling, or by variation of other parameters.

These results are at once of importance in the design of vibration mills, because it is evident that for the most rapid grinding the condition:

$$\left(\frac{\omega^2\alpha}{g} - 1\right) = 2n \qquad \ldots.(6)$$

where n is any integer >0 must be observed. If this is not done, it is possible that the mill will be grinding less rapidly than when it is running at a lower speed. (Note the point 2900 rpm on Fig. 4, corresponding to $\left(\frac{\omega^2\alpha}{g} - 1\right) = 6.2$, is higher than that at 3100 rpm, corresponding to $\left(\frac{\omega^2\alpha}{g} - 1\right) = 7.2$.) Thus, a random increase in the speed of a mill does not necessarily improve the performance. For properly chosen speed conditions, however, with $n > 1.0$, the rate of grinding increases approximately as the cube of the frequency. If $0 < \left(\frac{\omega^2\alpha}{g} - 1\right) < 2.0$, the rate of grinding increases even more rapidly with the speed.

From this analysis it follows that worth-while gains in the rate of grinding are to be obtained by the use of frequencies which are of such a magnitude as to offer no technical difficulties.

Thus, for example, a normal vibration mill has a speed of about 1500 cycles/minute and, under the conditions of the present test, this leads to a rate of surface production of about 250 cm²/gm/hr. If, however, the speed is increased to 3000 cycles/minute the rate of milling is increased eightfold; to 2000 cm²/gm/hr. Furthermore, although the test has not actually been carried out, it appears reasonable to believe that if the speed were increased to 6000 cycles/minute, which would still be within the bounds of possibility, the rate of grinding would be increased about sixty-four-fold, giving the phenomenal figure of 16,000 cm²/gm/hr for the grinding of quartz!

The Groups (b/α) and (d/α)

These groups can be most conveniently studied at the same time, use being made of data relating to the rate of milling with balls of various sizes when all the other variables are maintained constant. When the rates of milling, for the different sizes of balls, are determined at various specified values of the specific surface (that is for known values of the mean particle size, b), the curves shown in Fig. 7 are obtained. It will be noticed that these curves do not pass through zero, but cut the horizontal axis at certain definite values. This means that the curves cannot be brought into coincidence by multiplying the ordinates of each curve by a simple factor; in other words, the rate of grinding is not a simple function of (b/α), since the required function of (b/α) would vary with the value of (d/α). If, however, the rates of milling are plotted against the corresponding values of (d/b) the curve of Fig. 8 is obtained. Here the points, although suffering some scatter, fall along a single curve and so it appears that the rate of milling is a unique function of (d/b).

Thus the functions $\varphi_3(d/\alpha)$ and $\varphi_4(b/\alpha)$ are replaced by the single function of (d/b) shown in Fig. 8. Furthermore, a rough plot shows that this function can be represented with considerable accuracy by the expression

$$\varphi(d/b) = K(d/b)^{\frac{1}{2}} \qquad \ldots.(7)$$

for values of (d/b) greater than 10; $\varphi(d/b) = 0$ for values of $(d/b) < 10$.

The result, that the rate of milling is zero for $(d/b) < 10$, would be expected, since in such cases the particles are not effectively trapped between the balls but are ejected from between the approaching surfaces.

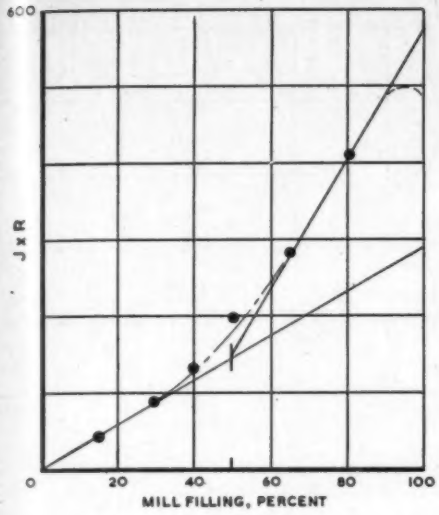


Fig. 13. Relation between mill filling and rate of production of total surface.

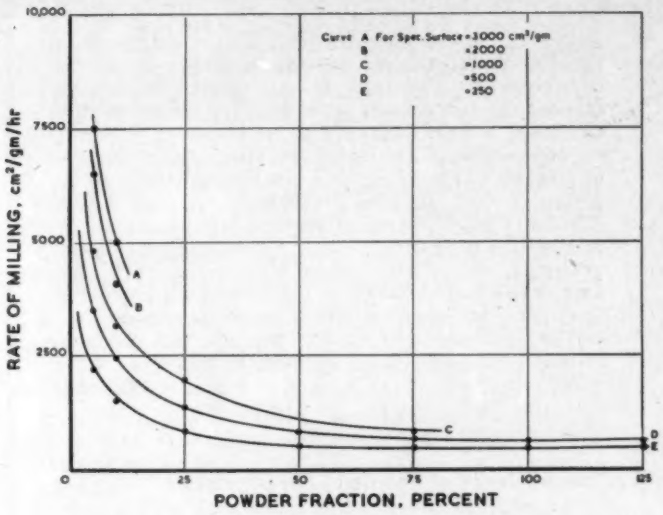


Fig. 14. Rate of milling in terms of powder fraction for values of the ratio ball diameter to particle diameter.

The Group (D/α)

The influence of the group (D/α) on the rate of grinding can be studied by the use of mill bodies of various sizes, and in Fig. 9 are given data relating to the specific surface produced, at various times, in mills of different diameters, all other variables being held constant. It can be seen that, with the exception of one point, the points fall well along a single curve. The single exception probably arises from some inhomogeneity in the feed material, or some similar random cause. Thus, it may be concluded that, over the range of sizes covered, the group (D/α) has no significant effect upon the rate of grinding, and so may be omitted. This result is rather surprising, because it would be expected that the greater forces required to accelerate the larger mass of balls associated with the larger mill bodies would lead to a higher rate of grinding, but this is, apparently, not so. It would therefore appear that the contact pressure is not an important variable in the crushing process.

The Mill Filling J

A curve, deduced in the manner described earlier, giving the rate of production of specific surface, for various values of mill filling is shown in Fig. 10, the quantity of powder being sufficient just to fill the space between the balls. Thus, $\varphi_6(J)$ is as shown in Fig. 11.

The rate of production of specific surface is approximately doubled by increasing the mill filling from 40% to 80% and so the rate of production of total surface, which is proportional to $J \times R$, is quadrupled. A plot of the rate of production of total surface with mill filling is given in Fig. 12, and this curve leads to Fig. 13. From the latter it is clear that, for fillings of less than 50%, the rate of production of total surface increases linearly with mill change. For fillings greater than 50% a further linear increment, proportional to the amount of charge greater than 50%, in excess to that obtained by extrapolation of the 0-50% curve arises.

It would appear that the straight line covering the range 0-50% arises from the upward projection of the charge, by the bottom of the mill body, followed by free fall. The extension of this line into the 50% to 100% range corresponds to the rate of grinding which would occur if the charge were increased into this range *and if free fall conditions were maintained.* In fact, however, when the charge exceeds 50%, the inward curvature of the walls of the mill projects the charge *downwards* and this contributes to the grinding due to upward projection. Thus, apparently the two actions are of approximately equal magnitude and are simply additive.

It appears, therefore, that a vibration mill with a cylindrical body should run with the shell very nearly full, sufficient room (say 10% of the mill volume) being allowed for an adequate dilation of the mill charge. This conclusion might, however, not be true for mills with bodies of other shapes.

The Powder Fraction U

For a given ball charge, the quantity of powder in the mill, and thus the dimensionless parameter U, may be varied. A set of curves showing the rate of milling, in terms of the powder fraction, for various values of the ratio (b/d) are given in Fig. 14. The rate of production of specific surface increases as the value of U decreases, a result fairly well known to practical mill operators.

Hence, a rapid production of a fine product can be obtained by milling with a reduced quantity of powder. It should be remembered, however, as pointed out by ROSE,[3] that this increased rate of grinding is obtained at the cost of an increased rate of metal wear. Thus, the function $\varphi_7(U)$ has the form given in Fig. 15.

The rate of production of total surface, Fig. 16, increases with increasing powder quantity and so, from the point of view of economical production, a high powder fraction is desirable. It is interesting to note that the equation of the line on Fig. 16 is

$$U \times R = 850\,[(1 - e^{-0.5\omega})\, e^{-0.5(1-e^{-0.5\omega})}\, e^{-0.1\omega^2}]^{0.4} \quad \ldots (8)$$

which is closely in accord with the form of the expression deduced theoretically for a ball mill by ROSE.[4]

The Influence of the Form of Oscillation

The influence of the form of oscillation upon the rate of grinding is of some interest and will now be considered. In Fig. 17 are shown a series of results for tests in which the vertical displacement is maintained constant at 0.4 cm, or in which the horizontal travel is varied whilst the vertical travel is maintained at this value, all the other

variables being unaltered between the tests.

A considerable amount of analysis has, so far, not revealed the relationship between the equivalent circular amplitude, and the magnitude of the horizontal and vertical components of the actual amplitude and so the rate of grinding corresponding to a non-circular motion is not, as yet, directly calculable. Nevertheless, the results summarised in this figure are of practical interest in that they suggest that the rate of milling decreases rapidly as the motion of the mill deviates from circular. These data suggest also that variations in the vertical amplitude have more influence upon the rate of grinding than do those in the horizontal motion and, therefore, the maximum vertical component should be used. It also appears that circular oscillation in a horizontal plane, which would consist of two horizontal motions of the type studied, would not give effective grinding.

The Influence of Powder Characteristics

The influence upon the rate of grinding of the characteristics of the feed material may be examined by milling, under specified conditions, of various types of material. In Fig. 18 are shown curves relating to the grinding of marble, quartz and corundum (fused aluminium oxide), the specific surface here being given in cm^2/cm^3. Thus the effects of density of the feed material are eliminated.

In Fig. 19 are given the corresponding curves for the rate of milling for different mean particle sizes. For small values of specific surface these curves approximate closely to the rate of milling, being proportional to the square root of the specific surface. Since, however, $b = 6/S_v$, this corresponds to the rate of milling being proportional to $(d/b)^{\frac{1}{2}}$; a result already obtained and expressed by Equation (7).

If, therefore, this portion of the curves are fitted by the equation $R_v = KS^{\frac{1}{2}}$, the constant K is, from Equation (3), inversely proportional to the material constant H. Hence, the value of H for each material may be estimated; the value for quartz being taken as unity. These data, together with reasonable values for the mineralogical hardness of these materials (on the extended scale of mineralogical hardness) are recorded in Table 1.

TABLE 1

Material	Hardness (Moh scale)	K	Relative value of H
Corundum	10-12	2.0	2.15
Quartz	7-8	4.3	1.00
Marble	4-5	10.2	0.42

A plot of these values of H, against the mineralogical hardness of the materials, is shown in Fig. 20. The points obtained by FAHRENWALD[5] are also given in the same figure and it is seen that all the available data fall well upon a single curve. The elongated form of point is used to indicate the range of uncertainty in the hardness of the materials. It is unlikely that the mineralogical hardness is decisive in the establishment of the grindability of a mineral, but the correlation presented here is of great interest and is probably a useful first approximation to the required relationship.

Grinding of Marble

Turning now to the other end of the size range—that is, to the high values of specific surface—the very marked decrease in the rate of grinding of marble is doubtless due to the very heavy ball coating which was observed

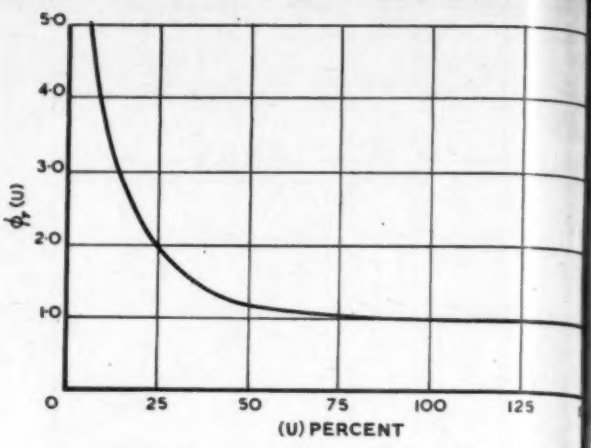


Fig. 15. Plot of function $\varphi_T(U)$ vs powder quantity in mill.

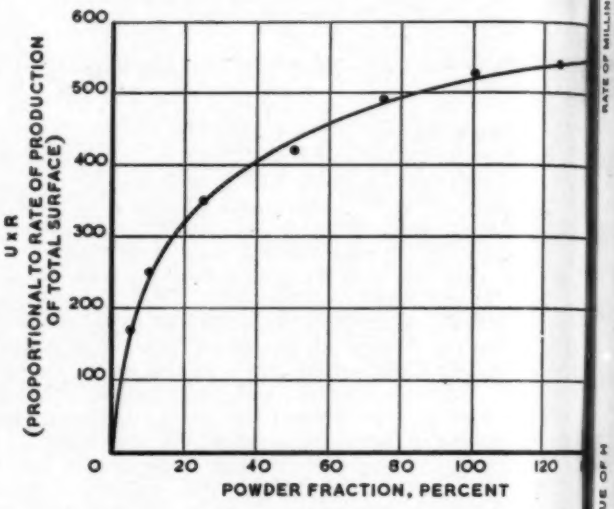


Fig. 16. Plot of rate of production of total surface vs. powder quantity in mill.

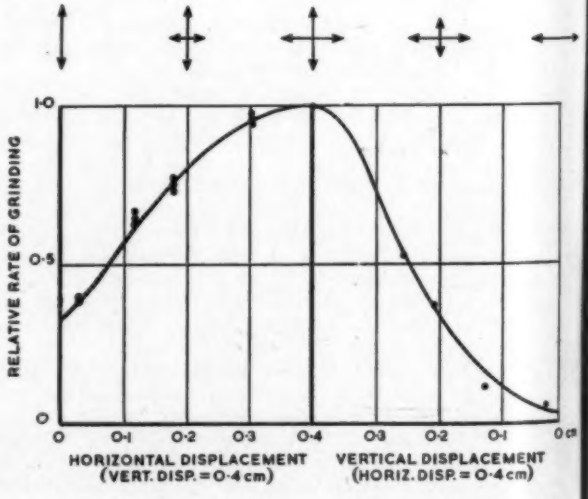


Fig. 17. Effect of form of oscillation of mill body upon rate of grinding.

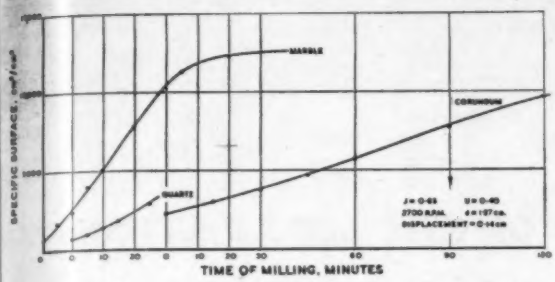


Fig. 18. Influence of properties of feed material upon rate of grinding.

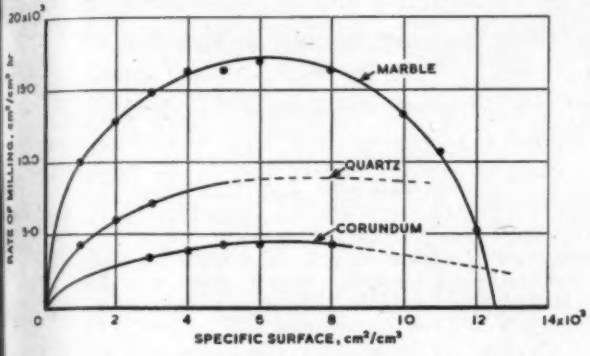


Fig. 19. Rate of milling vs. specific surface sizes for different materials.

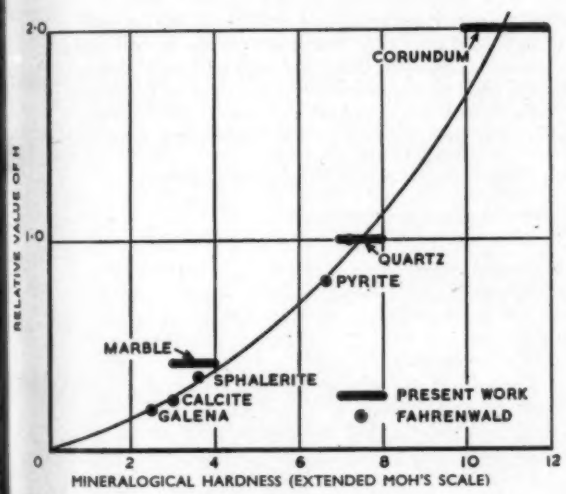


Fig. 20. Relation between material constant and hardness.

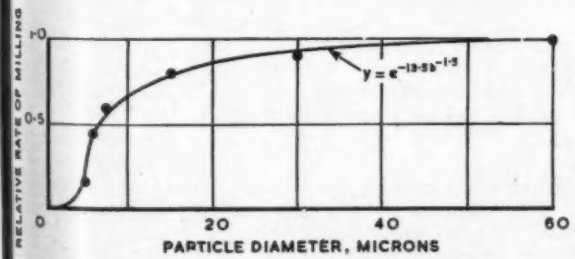


Fig. 21. Influence of ball coating upon rate of milling, derived from data on grinding of marble.

to occur with this material. Furthermore, no appreciable ball coating occurred with the other materials and this decrease in grinding rate is scarcely encountered, there being a suggestion of the onset of this condition with the corundum.

There are not sufficient data available to permit a comprehensive analysis of the influence of ball coating upon the rate of grinding, but a curve deduced from the data for the grinding of marble is shown in Fig. 21. From this it is seen that the relationship between the influence of the ball coating and the particle diameter is roughly of the form

$$Z = e^{-Ab^{-1.5}} \qquad \ldots . (9)$$

where Z is the factor by which the rate of milling expression must be multiplied when ball coating occurs. Even so, grinding almost ceases when the mean particle size is about 5 microns. The value of the parameter A would, doubtless, depend upon factors such as the cohesive strength of the powder.

To sum up, it appears that with materials, such as marble, the ball coating can have an appreciable effect upon the rate of grinding for particle sizes as large as 30 microns. For materials such as quartz or corundum, however, such effects are negligible for materials of size greater than about 10 microns.

The Final Equation

In order to allow the calculation of the rate of milling from the foregoing results, it is necessary to introduce the functional relationships into Equation (3), together with a multiplicative constant, the value of which is known.

In this way Equation (3) reduces to:

$$\left(\frac{R\,\delta\,\alpha}{\omega}\right) = K \times \left(\frac{\omega^2\,\rho\,\alpha^3}{H}\right) \times (d/b)^{\frac{1}{2}} \times \varphi_2\left(\frac{\omega^2\,\alpha}{g}\right) \times \varphi_6(J) \times \varphi_7(U) \qquad \ldots . (10)$$

for circular motion of the mill and for $(d/b) > 10.0$.

Here H may be deduced approximately from Fig. 20; $\varphi_2\left(\frac{\omega^2\,\alpha}{g}\right)$ is obtained from Fig. 6, $\varphi_6(J)$ from Fig. 11 and $\varphi_7(U)$ from Fig. 15.

The value of the constant K can be evaluated, at least theoretically, for any single known set of conditions, but in practice the mean value for a number of sets of conditions is more reliable. The value so obtained for six points is $K = 2.75 \times 10^{-8}$ ($\pm 8\%$) and so

$$\left(\frac{R\,\delta\,\alpha}{\omega}\right) = 2.75 \times 10^{-8} \left(\frac{\omega^2\,\rho\,\alpha^3}{H}\right) (d/b)^{\frac{1}{2}} \times \varphi_2\left(\frac{\omega^2\,\alpha}{g}\right) \times \varphi_6(J) \times \varphi_7(U)$$

in C.G.S. units. (Note: R is then in cm²/gm. sec.) If the motion of the mill bodies is not circular, an approximate correction to the rate of grinding could be made by the use of Fig. 17.

REFERENCES

[1] Rose, H. E. *J. App. Chem.*, 1952, **2**, 217.
[2] Tyler, P. M. F.I.A.T. Final Report, No. 754, 1946 (London, H.M.S.O.).
[3] Rose, H. E. *Trans. Inst. Chem. Eng.*, 1957, **35**, 87.
[4] Rose, H. E. Loc. cit. [3].
[5] Fahrenwald, W. *Trans. Amer. Inst. Min. Met. Eng.*, 1934, **112**, 94.

ACKNOWLEDGMENT

The authors wish to express their thanks to Mr. C. G. Blaker, of the Blaker Motor & Welding Co., for advice in connection with the design of the machine, and in particular in relation to the parts which were fabricated from aluminium alloy by argon welding, and to that company for the care exercised in the construction of major portions of the machine.

Thanks are also due to the Department of Scientific and Industrial Research for the provision of a Research Fellowship which made this work possible.

621.926.7 : 621.928.8

DRY GRINDING AND DRY MAGNETIC SEPARATION OF MAGNETIC IRON ORES*

Better metallurgical results, cheaper transport and cheaper buildings are all claimed advantages of avoiding wet processing methods

by EDVIN B. JOHANSON†

RECENTLY, both in Scandinavia and in America, there has been a considerable interest in beneficiation of magnetic iron ores by dry grinding and dry separation. Many Scandinavian ores are a mixture of magnetite and hæmatite, and it is planned at several mines to adopt dry grinding as the first step and the concentrating of the magnetic part on dry separators as the second step. The rest will be re-ground and treated separately by wet concentration or by flotation.

The main difference between wet separation and dry magnetic separation is that dry magnetic separators offer the possibility of a middling product, which is practically impossible with wet separation. With magnetic separators it is also possible to get a coarse product in the first step, which is very desirable for sintering.

Dry Grinding

In Scandinavia most of the dry plants have been planned with peripheral-discharge rod mills. This paper will only indicate some design points of these mills.

In order to get a wide opening for charging the mill, this is designed with a roller bearing trunnion at one end and supporting rollers at the other end at the charging end. The trunnion at the discharge end is hollow for feeding the rods to the mill. A hood surrounds the discharge ports to confine dust. Here it should be stressed, that the

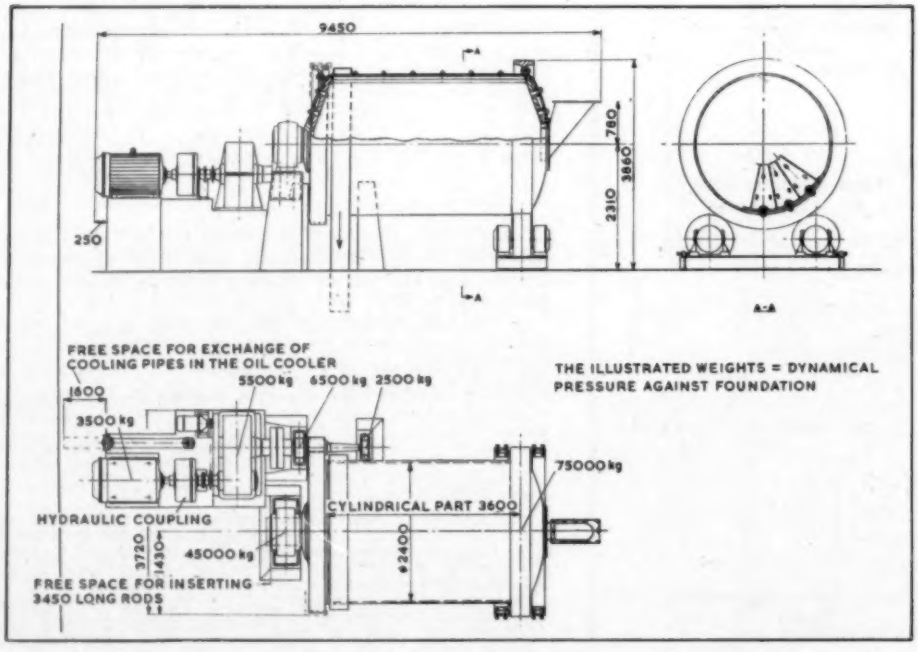


Fig. 1. Details of a typical 8 ft × 12 ft rod mill with peripheral discharge.

* This paper was presented at the Crushing and Grinding Symposium, arranged by the Norwegian Engineering Society in Oslo, October 20 and 21, 1958.

† Sala Maskinfabriks A.B., Sweden.

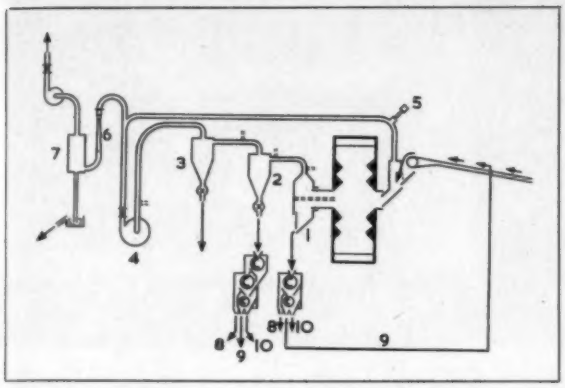


Fig. 2. Aerofall mill dry grinding circuit with magnetic separators.

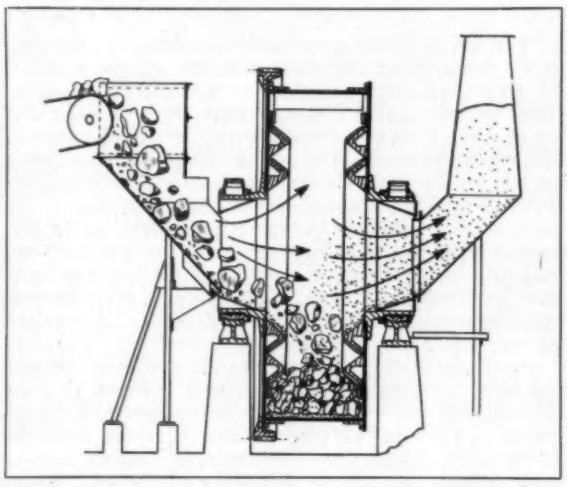


Fig. 3. Aerofall mill cross-section, showing the feeding arrangement and withdrawal of fine particles.

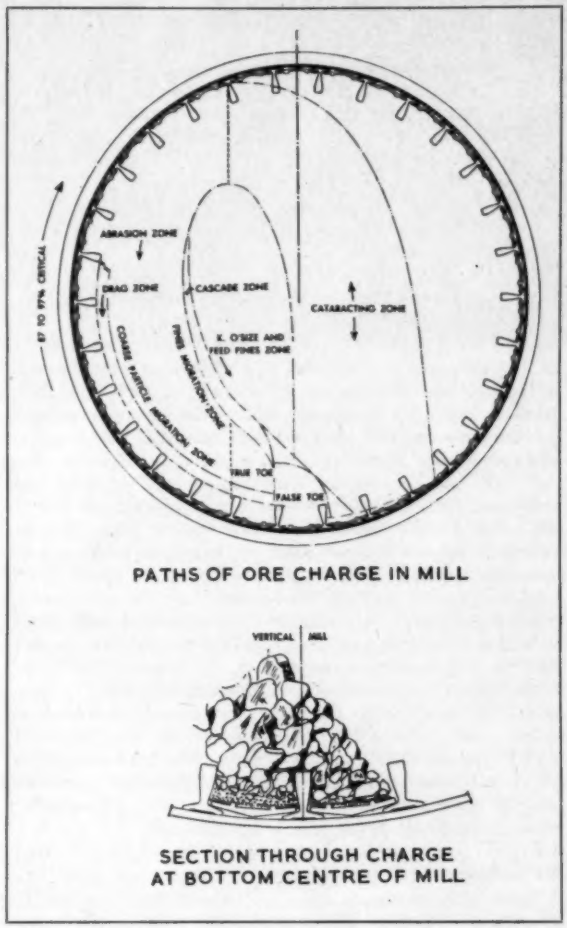


Fig. 4. Diagram showing paths taken by ore during the grinding process, and return of oversize to mill. Below, the crushing action which takes place at mill base.

dust problem is a very important factor to consider when planning a dry grinding plant. Everything must be carefully planned to keep the dust in, and the conveyors between the different points must also be dust-tight.

The cohesive forces between finely ground particles cause them to adhere to each other, and therefore to flocculate. The effectiveness of separation can substantially be greatly improved by drying the feed to make it more easily dispersed. For dry magnetic separation it has proved necessary to keep the moisture under 0.5%. Through grinding, some of the water is evaporated so that the allowable moisture content of the feed to the mill can usually be about 1.5% H_2O.

According to RUNOLINNA[1] the separation can be improved by adding about 250-500 g./ton of tall oil to the charge in the mill.

Most of the water in the crushed feed to the mill is usually surface water and it has in some cases proved advantageous to screen off the fines holding most of the water and to dry this part separately before grinding it.

Aerofall Mill

The Aerofall mill is an outstanding example of a dry, combined crushing and grinding machine. It is capable of taking the discharge of a coarse crusher or run-of-mine material as feed and reducing it in a single crushing and grinding unit to the desired size. Air classification is employed to remove the finished material from the mill. The entire system is held under a partial vacuum, making a dust control system for the plant unnecessary, as far as the mill itself is concerned.[2]

The great advantage with the Aerofall mill is that crushing and grinding are done in one step from run-of-mine feed and ahead of the mill all the secondary crushing with screens and conveyors is abandoned. The wearing costs are also lower than with the conventional systems of crushing, screening and grinding. Thus, at Benson Mines, New York State, N.Y., the wear was at one time 0.7 lb./ton, but with the Aerofall mill the wear is only 0.07 lb./ton.

Fig. 2 shows a milling flow sheet for the Aerofall mill. The complete system is held under a partial vacuum, and the ground particles are carried away with the air stream from the mill. The particles pass first of all to an air classifier (1), where the heaviest particles are caught; the fines continue to the cyclone (2), leaving the finest dust to be caught in a multiclone (3). From this the air passes through a suction fan (4) and the greater part of the air is returned to the mill and heated at (5). A fraction of the air is bled from the system through a Venturi-scrubber (6)

with a moisture trap (7) before passing out through the chimney.

At Benson Mines a 17-ft Aerofall mill handles 140 ton/hr of feed crushed to 8 in. and reduces it to 100% −10 mesh. The h.p. of the complete installation is 800. Another mill, this time a 22-ft machine, in operation at Mangola, Southern Rhodesia, reduces 12-in. run-of-mine copper ore to 85% −200 mesh at a rate of 62 ton/hr. Power consumption is 15 kWh/ton as against 23 kWh/ton for conventional crushing and grinding.

Aerofall Mill Principle

The basic feature of the mill is the continuous dry crushing and grinding action of the ore upon itself, combined with classification of the ground material by-passing air through it at a controlled rate of flow. As the Aerofall mill combines crushing and grinding in a single operation, several stages of crushing, which precede conventional grinding equipment, become unnecessary.[3] To cite an example of the foregoing, one particular installation of an Aerofall mill is taking run-of-mine ore −18 in. and reducing it in a single operation to a product as fine as 60% −200 mesh. It should be pointed out here that, if a coarse grind is required, the controlled air flow through the mill can be varied to give a product in the 10-mesh range. The mill operates in conjunction with air-operated product-recovery apparatus in a completely closed system.

Depending upon the final recovery system (wet or dry) used in any particular installation, the product discharged from the mill is fed directly into wet or dry apparatus and is carried on through the various stages of the system to final product recovery. With regard to the allowable moisture content of initial ore feed, it has been determined from tests and actual operation results that the mill will tolerate a moisture content of 3½ to 4% without any effect upon the capacity or the grind characteristics.

Dry Magnetic Separation

Soon after the last war TAGE MÖRTSELL designed his first dry magnetic separator equipped with permanent magnets of the same type as those now in use. MÖRTSELL was at that time assistant at the Ore Dressing Laboratory at the Royal Technical Institute in Stockholm. He built up a magnet wheel carrying permanent magnets of alternating polarity placed as close to each other as possible. This magnetic wheel was surrounded by a stainless-steel drum and arranged so that the magnet wheel could be driven independently of the drum. The material was fed on top of the drum and the concentrate removed by an induction roller. MÖRTSELL soon found that having the magnet wheel stationary made little difference to the performance and consequently he removed some of the magnets around about a quarter of the circumference, thereby simplifying the design. This was also adopted as standard on account of its simplicity. The arrangement of the magnets is shown in Fig. 5.

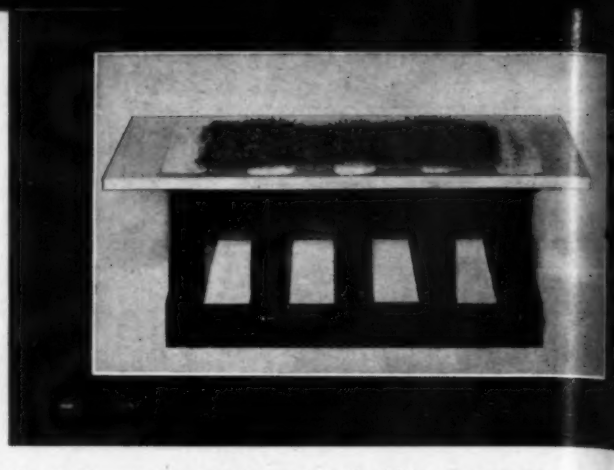


Fig. 5. Permanent magnets used in the Mörtsell separator. The picture shows how the material passes over between the poles.

When the drum rotates outside the stationary magnet wheel, the magnetic material turns over between the poles and in this way separates the non-magnetic particles, which then are thrown off the drum. The material is fed to the drum either with a belt feeder or over a vibrating feeder which must be so designed that the feed is distributed evenly over the whole length of the drum. At

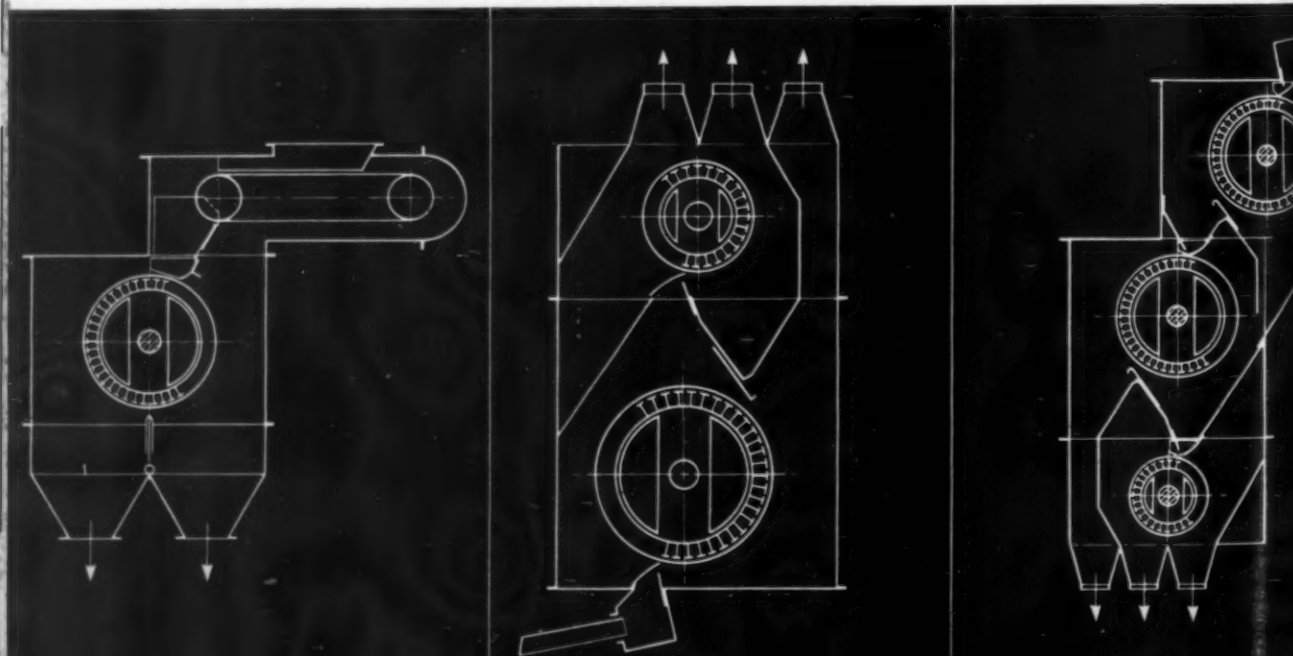


Fig. 6. Three diagrams illustrating different arrangements of a dry magnetic separator:
(a) single drum. *(b) two drum.* *(c) three drum.*

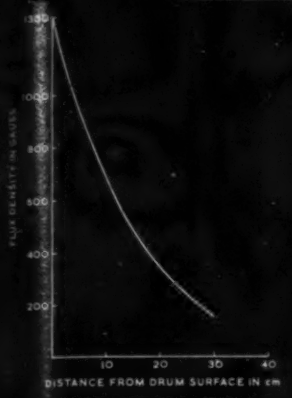


Fig. 7. Effect of distance from drum surface on strength of magnetic field for magnetic separator.

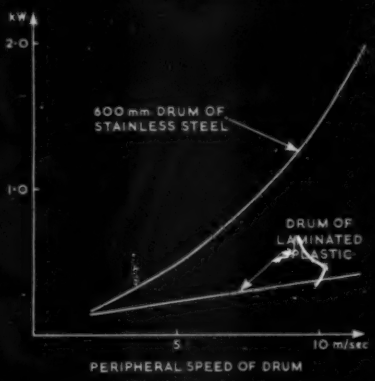


Fig. 8. Variation of power consumption with drum rotation for stainless-steel and plastic drums.

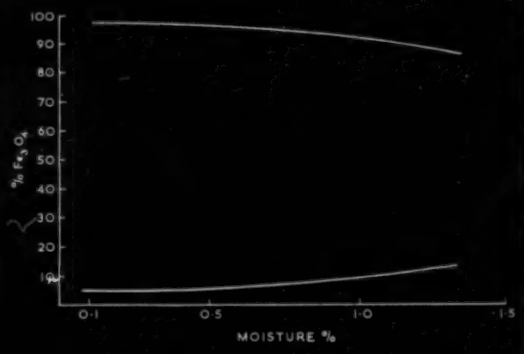
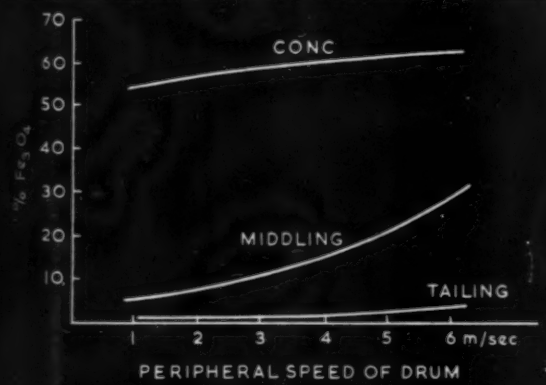


Fig. 9. Diagram illustrating the effect of moisture content of feed upon magnetic separation.

present these separators are built with a length of drum of up to 1.5 m. The separator has two discharge points, one for the tailing and one for concentrate; the concentrate leaves the drum at the end of the stationary magnets.

In this case the top drum is 600 mm in diam. and rotates relatively slowly. The drum should leave a clean tailing. The concentrate moves on to the next drum which is 400 mm in diam., and which rotates at a higher speed. Here the middlings are thrown off by the centrifugal force, leaving a high-grade concentrate on the drum. The middling is usually returned for regrinding. Naturally the drum has a critical speed at which also the particles of magnetite should be forced to leave the drum. For a 400-mm drum this critical peripheral speed is about 7 m./sec. and for a 600-mm drum about 8 m./sec. The 600-mm drum is run quite slowly to leave a clean tailing and the speed here usually is about 2 to 2.5 m./sec. The bottom 400-mm drum is driven through a variable-speed reducer so as to control the concentrate and the middling; usually the peripheral speed here is about 5 to 6 m./sec., and in some cases higher.

Fig. 10. Influence of drum speed upon the quality of the separated fractions.



MAGNETIC TEST OF TAILINGS	
PERIPHERAL SPEED	MAGNETITE
1·0 m/sec	0·06 %
1·8 "	0·15 %
3·5 "	0·58 %
6·0 "	2·03 %

Fig. 8 shows a separator with three drums where the two upper drums of 600 mm in diam. have a relatively slow peripheral speed, and the bottom 400-mm drum revolves more rapidly. The tailing from the first drum passes on to the second drum, which will leave a tailing practically free from iron. The concentrate from these two drums is treated on the last drum to give a high-grade concentrate and a middling.

A number of different materials have been experimented with for the drums themselves. Tests have shown the difference in power consumption between a drum of stainless steel and one made of laminated plastic. At slow speed the difference is hardly noticeable, but at high speed the difference is considerable, as the curves of Fig. 8 show. Among the other factors affecting the operation of magnetic separators of this kind are the moisture content of the feed, the speed of rotation of the drums and the strength of the magnetic field. The effects of these variables are shown in Figs. 7, 9 and 10. They emphasise the importance of having a dry material and of selecting correctly the speed of the drum.

Magnetic Roasting of Hæmatite Combined with Dry Separation

In this connection we must mention the research work of Bo Kalling and Sven Eketorp at Domnarfvets Jernverk, in Sweden, on magnetising roasting of hæmatite combined with dry magnetic separation. A paper describing this work was presented by Eketorp[3] at the Mineral Dressing Congress in Stockholm, 1957. This research work is still going on and it is likely that the oil consumption will be about 12-15 l. oil/ton ore, a promising result which may be of great significance for the future treating of hæmatite. The advantages of this method are apparent, as the reduction of hæmatite to magnetite will give a higher recovery and coarser concentrate and a better material for sintering.

Examples of Dry Grinding Plants with Magnetic Separators

A number of plants today use dry grinding in conjunction with magnetic separation. Thus at Mine A the feed is about 15 tons/hr of −40-mm magnetite. The separator, which has two drums, gives three products: tailing, concentrate and a middling which is returned for regrinding. The essentials of the process are shown in Fig. 11.

Mine B is another example (Fig. 12). This shows a flowsheet for a greater capacity where the feed to the separators is divided among several units. Before milling everything less than −10 mm is screened off, and this portion

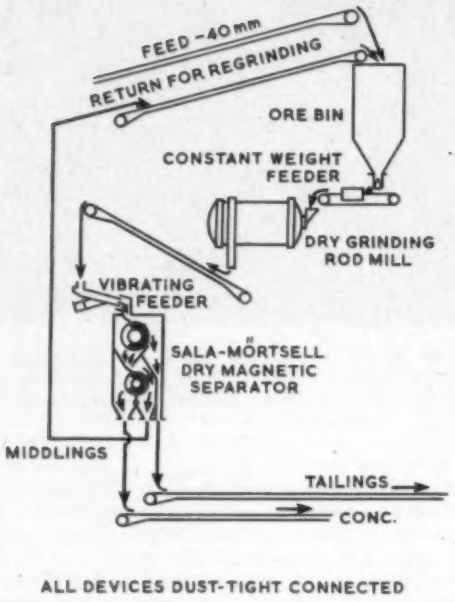


Fig. 11. Flow diagram for Norberg dry ore concentrating plant for magnetite.

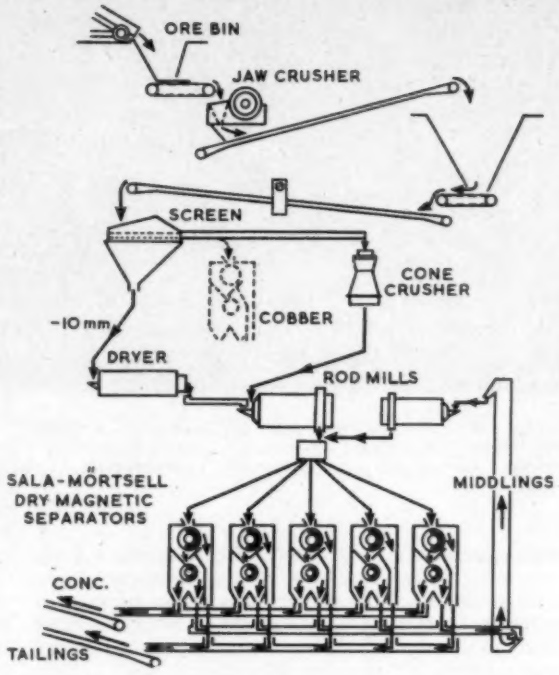


Fig. 12. Flow diagram of plant equipped with several magnetic separators.

is dried before milling. This gives a ground product containing <0.5% water. The middling from the separators is re-ground in a separate rod-mill.

Mine C has a capacity of about 50,000 tons per year of magnetite with some hæmatite, giving a combined composition of 35.1% Fe and 0.07% P. This is a small mine which has just started up, and to save the expense of the dryer all material less than 6 mm is screened off to be treated later. The ore is ground down to 90% −1.2 mm. After laboratory tests it has been calculated that the concentrate will hold 63% Fe and <0.01% P for a recovery of 95% of the total iron. Tests have been carried out with wet separation and comparison shows that dry separation gives a better concentrate with lower P-content; this comparison applies to material taken from a single grind.

Finally, a general case is shown (Fig. 2) where the grinding is carried out with an Aerofall mill. The flow-sheet is typical only, as an actual flow-sheet would depend upon the ore and also upon the concentrate desired. Middlings from the last separator are re-ground and re-separated.

Dry grinding and dry separation have a number of important advantages when compared with wet processing methods. Thus there is no water problem. In cold climates this is a very important factor (in wet plants processing low-grade magnetite ores about 3 to 4 tons of water is required per ton of concentrate produced). The concentrate can be transported the year around and stockpiled either at the ore-dressing plant or at the harbour. Furthermore, transport, both on land and sea, is cheaper as are the buildings for the ore-dressing plant, since heating is not required. Better metallurgical results also are obtained since a coarser product for sintering results; capacity per machine unit is higher, and tailings are less of a problem.

REFERENCES

[1] Runolinna, U. "Dry Magnetic Separation of Finely Ground Magnetite", *Trans.* International Mineral Dressing Congress, Stockholm, 1957.
[2] Fleck, R. G. "Low-grade Iron Ore and the Aerofall Mill", Crushing and Grinding Session Mineral Beneficiation Division, A.I.M.E., February, 1958, New York.
[3] Eketorp, S. "Magnetic Roasting of Hæmatite." *Trans.* of the International Mineral Dressing Congress, Stockholm, 1957.

Production Scheme of Erdoelchemie

IN a recent lecture DR. K. W. SCHNEIDER indicated the general scope of the new German firm Erdoelchemie of Dormagen, which was set up in March, 1957, as a joint undertaking of Farbenfabriken Bayer A.G. of Leverkusen and BP Benzin & Petroleum A.G. of Hamburg—a subsidiary company of the British Petroleum Co. of London. Its field of activities lies between that of the mineral oil industry and the chemical industry. Raw materials will be supplied exclusively through B.P. The production scheme can be based on crude oil or a fraction. Economic appraisal has led to a decision to use the light gasoline fraction as the starting point.

In the first stage the gasoline will be cracked into ethylene, propylene, butadiene, methane and hydrogen. A part of the gasoline will be improved in its properties, forming a high-grade motor fuel. Two cracker plants will be operated in parallel. One is a Lurgi-Ruhrgas cracker with relatively great flexibility in respect of feed stock and composition of olefins produced. In this, hot sand will be used as the heat carrier cracking the gasoline at 700-800°C with a capacity of 65,000 tons a year. Most of the gases will then be liquefied in a gas separation plant and fractionated at temperatures down to −150°C. There will also be a steam cracker using tube furnaces with a throughput of 200,000 tons of gasoline a year of the same type as installed in Grangemouth by B.H.C. Ltd.

The combined ethylene production will be 45,000 tons a year to be used mainly in making ethylene oxide and ethyl alcohol. Propylene will be used for making propylene oxide and foamed plastics. The C_4 hydrocarbons will be going to Bayer for manufacture of Perbunan-N and to Hüls for cold rubber (GRS).

621.928.1:512.831

CALCULATION OF CLOSED-CIRCUIT GRINDING

How to calculate the characteristics of a product obtained from a recycle size reduction process by means of matrix algebra

by R. L. BROWN, M.A., M.I.Chem.E., F.Inst.P., F.Inst.F.

IN processes in which one or more feedstocks pass through a series of operations and emerge as one or more product and effluent stocks, it is not difficult to calculate the characteristics of the product from data on the performance of the equipment installed for each individual operation. When some of the material is recycled, so that there is a closed circuit (or circuits), it becomes necessary to solve simultaneous equations in order to find what product emerges. This paper is concerned with the use of matrix algebra as a tool for making such calculations.

Data on the individual operations in the whole process are often represented by continuous curves. If equations are fitted to these curves, closed-circuit systems are often found to yield complicated integral or differential equations, the solution of which can be troublesome. The mathematical difficulties can be avoided by a matrix method, provided it can be assumed that the original experimental data can be represented adequately by a histogram, rather than a continuous curve.

The matrix method was introduced by BROADBENT and CALLCOTT,[1] who set up the equations for closed-circuit grinding and classification. In this application the feedstock is characterised by its sieve analysis. The series of numbers corresponding to the fractions lying between adjacent sieves is treated as a vector. Thus the vector (55, 21, 13, 11, 0, 0) gives the percentages lying between a chosen series of sieves, viz., +10, 10 × 18, ..., 100 × 200, −200 B.S. mesh. Likewise the product is represented by its sieve analysis or a vector. Since the sieve analysis is an adequate description of the product in a large number of practical cases, the approximation introduced by not using a functional form for the size distribution curves is clearly justifiable. Moreover, the number of sieves determines the detail of the answer obtained and the calculations correspond precisely to the choice of this number. To illustrate the method, a problem in closed-circuit grinding is described and solved.

Examples of Matrices

CLASSIFYING MATRIX

The performance of apparatus for classifying particles by size is well represented by its grade efficiency, namely, the fraction of each size grade included in the fine product. Some typical data are given in Table 1. Here C_{11} is the grade efficiency on the +10 B.S. mesh fraction, C_{22} on the 10 × 18 mesh fraction, and so on.

Table 1—Grade Efficiency of a Classifier

Size grade, B.S. mesh	+10	10×18	18×36	36×100	100×200	−200
Arithmetic mean size, μ	—	1264	638	284	114	—
Grade efficiency	C_{11}	C_{22}	C_{33}	C_{44}	C_{55}	C_{66}
Classifier α	0.00	0.05	0.14	0.39	0.80	0.90
Classifier β	0.01	0.11	0.30	0.56	0.93	0.97
Feed, lb./hr.	p_1	p_2	p_3	p_4	p_5	p_6
Output of fines, lb./hr.	q_1	q_2	q_3	q_4	q_5	q_6

The data given for classifiers α and β were found in laboratory experiments aimed at the design of a combined mill and classifier that would yield a product specified in terms of the mesh sizes set out in row 1.

If p_i lb./hr of material in the i^{th} size grade is fed to the classifier, yielding q_i lb./hr of material in the i^{th} grade in the fines output; then by definition:

$$q_i = c_{ii}\, p_i \text{ all } i = 1, \ldots, 6 \qquad \ldots . (1)$$

If we write:

$$\mathbf{C} = \begin{pmatrix} C_{11} & 0 & 0 & 0 & 0 & 0 \\ 0 & C_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{pmatrix} \qquad \ldots . (2)$$

then this square array is a matrix such that:

$$\mathbf{q} = \mathbf{C}\ \mathbf{p} \qquad \ldots . (3)$$

where the feed is the vector $\mathbf{p} = (p_1, p_2, p_3, p_4, p_5, p_6)$ and the fines output the vector $\mathbf{q} = (q_1, q_2, q_3, q_4, q_5, q_6)$. The rules (see Appendix) for multiplication of vectors by matrices, given in school textbooks of advanced algebra, show immediately that Equations (1) and (3) are identical.*

Because **C** is a diagonal matrix, with zero for every element not on the diagonal, Equation (3) is no more convenient or compact than Equation (2). But the representation (3) turns out to be useful when we come to closed-circuit grinding. It should be remarked that the matrix **C**

* Thus the *fourth* element of **q** is found by multiplying each element in **p** by the corresponding elements in the *fourth* row of **C** and adding the products together.

characterises the performance of the classifier. When the performance is substantially independent of the feed (either rate or sieve analysis) the calculations are much simplified. It will be assumed here that **C** does not depend on **p**; there is some experimental evidence that this is a valid assumption for the machine under investigation.

Grinding Matrix

The columns in Table 2 give the rate at which each size grade is produced, in one pass through a mill, from a feed of each of the size grades set across the top of the table. The data are for each size grade fed separately. It has been shown[3] that a feed consisting of a mixture of the size grades can be calculated from the breakage of each size grade, provided that the mixed feed is fed at a rate equal to that at which each size grade was fed when the data in the columns of Table 2 were determined.** Since the individual size grades were fed at a rate of the order of 50-100 lb./hr, a mixed feed (k_1, k_2, ..., k_6) yields a product calculable from Table 2 if it is also fed at 50-100 lb./hr. Thus k_1 lb./hr of +10 B.S. mesh yields a product k_1 (0.40, 0.02, 0.02, 0.09, 0.14, 0.33) lb./hr in each of the size grades +10, 10 × 18, ..., −200 B.S. mesh. Furthermore, the amount of 36 × 100 B.S. mesh material in the product is given by (0.09 k_1 + 0.04 k_2 + 0.08 k_3 + 0.91 k_4). Thus if the square array in Table 2 is represented by the matrix:

Table 2—Performance of a Mill with a Closely Graded Feed

Size of feed, B.S. mesh	+10	10×18	18×36	36×100	100×200	−200
Sieve analysis of product,						
+10	.40	.	.	.	.	.
10×18	.02	.59	.	.	.	.
18×36	.02	.04	.65	.	.	.
36×100	.09	.04	.08	.91	.	.
100×200	.14	.08	.07	.02	1.00	.
−200	.33	.25	.20	.07	.00	1.00

$$\mathbf{M}=\begin{pmatrix} m_{11} & . & . & . & . & . \\ m_{21} & m_{22} & . & . & . & . \\ m_{31} & m_{32} & m_{33} & . & . & . \\ m_{41} & m_{42} & m_{43} & m_{44} & . & . \\ m_{51} & m_{52} & m_{53} & m_{54} & m_{55} & . \\ m_{61} & m_{62} & m_{63} & m_{64} & m_{65} & m_{66} \end{pmatrix} \quad \ldots.(4)$$

Then the product **p** from a feed **k** to the mill is given by:

$$\mathbf{p} = \mathbf{Mk} \quad \ldots.(5)$$

A • is written for those elements in the upper half of the matrix that are identically zero.

Here **M** is a lower triangular matrix. The rule (see Appendix) for multiplying matrices into vectors gives immediately the elements of **p**. For example, the weight of product in the size grade 36 × 100 mesh is (m_{41} k_1 + m_{42} k_2 + m_{43} k_3 + m_{44} k_4) lb./hr.

Closed-circuit Grinding

Theory

Consider now the system shown in Fig. 1, where a make-up **m** is mixed with oversize (**p** − **q**), rejected by a classifier and fed to a mill, and the product **p** from the mill then passes to the classifier.

Obviously in the steady state,

$$\mathbf{k} = \mathbf{m} + \mathbf{p} - \mathbf{q} \quad \ldots.(6)$$

this vector equation replacing the six equations

$$k_i = m_i + p_i - q_i \quad i = 1 \ldots 6 \quad \ldots.(7)$$

each of which is a weight balance of one of the size grades. The remaining Equations are (3) and (5), viz.:

$$\mathbf{p} = \mathbf{Mk},\ \mathbf{q} = \mathbf{Cp}$$

Multiplying Equation (6) by **M** and using Equations (3) and (5), we find:

$$\mathbf{Mk} = \mathbf{Mm} + \mathbf{Mp} - \mathbf{Mq}$$
$$= \mathbf{Mm} + \mathbf{Mp} - \mathbf{MCp}$$

Since the left hand is $\mathbf{p} = \mathbf{Ip}$, where **I** is the unit matrix, it follows that:

$$(\mathbf{I} - \mathbf{M} + \mathbf{MC})\mathbf{p} = \mathbf{Mm} \quad \ldots.(8)$$

Notice that in matrix multiplication it is not permissible to change the order of writing down the product of two matrices.*

$$\text{Write } \mathbf{G} = (\mathbf{I} - \mathbf{M} + \mathbf{MC}) \quad \ldots.(9)$$

and $\mathbf{G}^{-1}$ for the inverse of **G**.

$$\text{Then } \mathbf{p} = \mathbf{G}^{-1}\,\mathbf{Mm}$$

Finally, using Equation (3), the output is given by.

$$\mathbf{q} = \mathbf{CG}^{-1}\,\mathbf{Mm} \quad \ldots.(10)$$

$$\text{or } \mathbf{q} = \mathbf{Hm} \quad \ldots.(11)$$

where **H** is the matrix $\mathbf{CG}^{-1}\,\mathbf{M}$.

Examples

The theory given above is simply a compact way of writing down sets of simultaneous equations in the eighteen unknowns k_i, p_i, q_i and then eliminating k_i, p_i so as to find the six q_i. The matrix **H** in Equation (10) describes the performance of the combined mill and classifier for *any* feed **m**, provided that changes in **m** do not affect the elements of **C** or **M**. This point, of course, is taken into account in devising appropriate laboratory experiments.

Consider now the mill and classifier ∝. We find easily:

$$\mathbf{MC}=\begin{pmatrix} 00 & . & . & . & . & . \\ 00 & 03 & . & . & . & . \\ 00 & 00 & 09 & . & . & . \\ 00 & 00 & 01 & 35 & . & . \\ 00 & 00 & 01 & 01 & 80 & . \\ 00 & 01 & 03 & 03 & 00 & 90 \end{pmatrix} \quad \ldots.(12)$$

where the figures are reported to two decimal places. In the calculations, it is best to keep three or four figures after the decimal place, rounding off to two places at the end. Then from Equation (9):

$$\mathbf{G}=\begin{pmatrix} 60 & . & . & . & . & . \\ -02 & 44 & . & . & . & . \\ -02 & -04 & 44 & . & . & . \\ -09 & -04 & -07 & 44 & . & . \\ -14 & -08 & -06 & -01 & 80 & . \\ -33 & -24 & -17 & -04 & 00 & 90 \end{pmatrix}$$

$$\mathbf{G}^{-1}=\begin{pmatrix} 1{,}67 & . & . & . & . & . \\ 08 & 2{,}28 & . & . & . & . \\ 08 & 20 & 2{,}27 & . & . & . \\ 36 & 22 & 35 & 2{,}25 & . & . \\ 31 & 23 & 18 & 03 & 1{,}25 & . \\ 66 & 65 & 45 & 11 & 00 & 1{,}11 \end{pmatrix} \quad \ldots.(13)$$

Next we find:

$$\mathbf{G}^{-1}\mathbf{M}=\begin{pmatrix} 67 & . & . & . & . & . \\ 08 & 1{,}34 & . & . & . & . \\ 08 & 21 & 1{,}47 & . & . & . \\ 36 & 24 & 41 & 2{,}05 & . & . \\ 31 & 25 & 20 & 06 & 1{,}25 & . \\ 66 & 68 & 52 & 17 & 00 & 1{,}11 \end{pmatrix} \quad \ldots.(14)$$

** The presence of different sizes in the mixed feed did result in some interaction, but this was small and has been neglected in this article.

* This is easily seen from the rule that the element in the i^{th} row and j^{th} column of the product matrix is the sum of the products obtained by multiplying the elements of the i^{th} row of the first matrix into the corresponding elements of the j^{th} column of the second matrix.

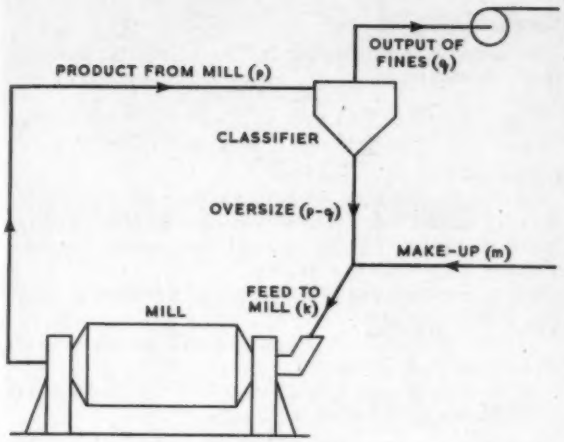


Fig. 1. Diagram used to illustrate the theory of closed-circuit grinding.

Fig. 2. Closed-circuit grinding tests under way at the plant of International Combustion Ltd., Derby.

$$\mathbf{H}=\mathbf{C}\mathbf{G}^{-1}\mathbf{M}=\begin{pmatrix} 00 & . & . & . & . & . \\ 00 & 07 & . & . & . & . \\ 01 & 03 & 21 & . & . & . \\ 14 & 09 & 16 & 80 & . & . \\ 25 & 20 & 16 & 04 & 1{,}00 & . \\ 60 & 61 & 47 & 16 & 00 & 1{,}00 \end{pmatrix} \quad \ldots\ldots(15)$$

Now if the rate of feed of one of the size grades, say +10 mesh, is unity, this grade is redistributed amongst all the sizes in proportion to the first column of **H**. Thus the sum of the elements of the first column (and of every other column) should be unity, for otherwise there would be an accumulation or disappearance of material in the circuit. This provides a convenient check on the arithmetic.

For a feedstock $\mathbf{m} = (55, 21, 13, 11, 0, 0)$ lb./hr, the rates at which each size grade moves through the circuit are given in Table 3. It will be seen that the feed to the mill, at 235 lb./hr, has size distribution (39, 22, 16, 18, 3, 2)%, while the product from the mill has size distribution (16, 14, 12, 22, 11, 25)%. For classifier β, which rejects as oversize less of the fines but more of the coarse than classifier α, the feed to the mill at 197 lb./hr has size distribution (46, 24, 14, 14, 1, 1)% and the product from the mill (18, 15, 11, 19, 11, 26)%.

The output of fines with classifier α has 54% through 200 B.S. mesh and 2% on 18 B.S. Mesh. With classifier β, the percentage through 200 B.S. mesh is 50 and there is 1% of material on 10 mesh. The main advantage of the higher efficiency of classifier β on through 100 B.S. mesh material as compared with α appears to lie in the lower weight of material fed to the mill (197 against 235 lb./hr) and the lower percentage of through 100 mesh in this feed. This would be likely to result in a lower power consumption in the mill, which has to be offset against the higher amount of oversize present in the fines output from classifier β as compared with α.

Conclusions

The example given above was calculated at one stage of a research and development programme and proved useful in showing clearly the direction of the further work necessary. The example shows how the performances of the mill and the classifier impinge on each other and help to set target figures for the performance of the mill and classifier separately which, together, would give an output having the desired sieve analysis.

Since their original paper,[1] BROADBENT and CALLCOTT have given further developments of this matrix method,[3] particularly useful in attempting to co-ordinate data obtained in different breakage processes. CALLCOTT[4] has extended the treatment to the case when a material has a multiple characterisation (namely, the ash contents in each of several size grades of coal) showing that investigations of processes aimed at achieving selective concentration of one of the characteristics of the material need careful planning if erroneous conclusions are to be avoided. The method is applicable when the characteristic of a material has a distribution which is altered in the process under consideration.

REFERENCES
[1] Broadbent, S. R., and Callcott, T. G. "A Matrix Analysis of Processes involving Particle Assemblies", *Phil. Trans. Roy. Soc.*, 1956 (19 April), Series A, **249**, No. 960, pp. 99-123.

Table 3—Rate of Movement of Each Size Grade in the Circuit

Place in Circuit	Symbol	+10	10×18	18×36	36×100	100×200	−200	Total lb./hr.
Make up	m	55	21	13	11	00	00	100
MILL ONLY								
Product	Mm	22	13	10	17	11	27	100
MILL AND CLASSIFIER α								
Feed to mill	k	92	51	37	43	06	06	235
Product from mill	p	37	32	28	52	26	60	235
Fines from classifier	q	00	02	04	20	20	54	100
MILL AND CLASSIFIER β								
Feed to mill	k	91	48	28	27	02	01	197
Product from mill	p	36	30	22	37	21	51	197
Fines from classifier	q	00	03	07	21	19	50	100

[5] Ellis, J., Ray, W. D. and Venables, J. "Further Work in the Matrix Analysis of Coal Breakage Processes", *Proc. of Inst. of F.* Conference: Science in the Use of Coal.
[6] Broadbent, S. R., and Callcott, T. G. "Coal Breakage Processes", Parts I-V, *J. Inst. F.*, December, 1956, and January, 1957:
Part I. "A New Analysis of Coal Breakage Processes", p. 524 (December, 1956).
Part II. "A Matrix Representation of Breakage", p. 528 (December, 1956).
Part III. "The Analysis of a Coal Transport System", p. 13 (January, 1957).
Part IV. "An Exploratory Analysis of the Cone Mill in Open-circuit Grinding", p. 18 (January, 1957).
Part V. "Analysis of Closed-circuit Grinding", p. 21 (January, 1957).
[7] Callcott, T. G. "A Matrix Analysis of 'Selective' Breakage Processes", *Proc. of Inst. of F.* Conference: Science in the Use of Coal.

ACKNOWLEDGMENT
This article is published with the permission of the British Coal Utilisation Research Association.

APPENDIX: RULES OF MATRIX ALGEBRA

We consider square matrices in which the number of rows is the same as the number of columns.

ADDITION

$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \pm \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} = \begin{pmatrix} a_{11} \pm b_{11} & a_{12} \pm b_{12} \\ a_{21} \pm b_{21} & a_{22} \pm b_{22} \end{pmatrix}$$

or in matrix notation: $\mathbf{A} \pm \mathbf{B} = (\mathbf{A} \pm \mathbf{B})$.

MULTIPLICATION

Multiply the elements of the rows of **A** into the columns of **B** and add, viz.

$$\mathbf{AB} = \begin{pmatrix} a_{11}b_{11}+a_{12}b_{21} & a_{11}b_{12}+a_{12}b_{22} \\ a_{21}b_{11}+a_{22}b_{21} & a_{21}b_{12}+a_{22}b_{22} \end{pmatrix}$$

Thus, in **AB**, the element in the i^{th} row and j^{th} column is found from the i^{th} row of **A** and the j^{th} column of **B**. For $n \times n$ matrices, the $(ij)^{th}$ element is

$$\sum_{s=1}^{n} a_{is}\, b_{sj} = (a_{i1}\, b_{1j} + a_{i2}\, b_{2j} \ldots, a_{in}\, b_{nj}) \quad \ldots . (A1)$$

Notice that $\mathbf{AB} \neq \mathbf{BA}$. The product **AB** is described as **B** premultiplied by **A**.

VECTORS

A vector **c**, premultiplied by the matrix **A** gives the vector **d**, where:

$$\mathbf{d} = \mathbf{Ac} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} c_1 \\ c_2 \end{pmatrix} = \begin{pmatrix} a_{11}c_1+a_{12}c_2 \\ a_{21}c_1+a_{22}c_2 \end{pmatrix}$$

DEFINITIONS

(a) *Lower Triangular Matrix:* All elements above leading diagonal are zero; viz.: if $a_{12} = b_{12} = 0$, then **A**, **B** are lower triangular. The product of two lower triangular matrices is itself lower triangular.

(b) *Diagonal Matrix:* All elements except those on leading diagonal are zero.

(c) *Unit Matrix*, **I**: A diagonal matrix in which every diagonal element is unity.

(d) *Inverse Matrix:* The matrix $\mathbf{G}^{-1}$ is the inverse of **G** if $\mathbf{G}^{-1}\mathbf{G} = \mathbf{G}\mathbf{G}^{-1} = \mathbf{I}$ the unit matrix. Thus in

$$\mathbf{Gp} = \mathbf{Mm}, \quad \ldots . (A2)$$

premultiplying both sides by $\mathbf{G}^{-1}$ gives

$$\mathbf{G}^{-1}\mathbf{Gp} = \mathbf{Ip} = \mathbf{p} = \mathbf{G}^{-1}\mathbf{Mm} \quad \ldots . (A3)$$

Thus the simultaneous Equations (A2) are solved in (A3) by calculation of $\mathbf{G}^{-1}$.

For lower triangular matrices it is particularly easy to find the inverse matrix. Thus if $\mathbf{G}^{-1}$ has elements g_{ij}, then for **G** as given in Equation (13) of the text the multiplication gives the terms on the right-hand side of Equation (A4), those on the left-hand side being the appropriate elements of the unit matrix, **I**.

$$\begin{aligned} 1 &= .60\, g_{11} & 0 &= .60\, g_{21} \\ 0 &= -.02\, g_{11} - .04\, g_{12} + .44\, g_{13} & 1 &= -.02 g_{21} + .44 g_{22} \\ 0 &= -.02\, g_{11} + .44\, g_{12} & 0 &= -.02 g_{21} - .04 g_{22} \end{aligned} \quad \ldots . (A4)$$

and so on. These simultaneous equations are rapidly and easily solved for the g_{ij}.

Safety, Health and Welfare

Chief Inspector of Factories Recommendations

IN his latest Annual Report,* the Chief Inspector of Factories has picked out for special comment developments in the use of organic peroxide compounds, now being introduced on a large scale. The largest increase in these has been in the field of polymerisation condensations. The peroxides are convenient sources of "free radicals" which act as initiators in polymerisations, especially those of the unsaturated bond type. One of the commoner reagents is benzoyl peroxide, obtainable as a dry powder, aqueous paste or as a paste in a plasticiser such as dibutyl phthalate. The dry material is sensitive to friction and heat and burns with extreme rapidity; the paste forms, however, are much less sensitive. Other peroxides commonly used include methyl ethyl ketone peroxide, cyclohexanone peroxide, lauroyl peroxide and cumene hydro peroxide. The report lists in detail the handling precautions to be taken.

Decontaminating Mercury Spillage

There is also advice on decontaminating areas where mercury has been spilt. This consists of treating the affected areas with a wash based on equal parts of slaked lime and flowers of sulphur liberally applied. Twenty-four hours later the wash is removed with clean water, and the surface allowed to dry. This method ensures that any microscopic droplets of mercury are converted into sulphide, so eliminating the danger of vaporisation from any material that cannot be mechanically removed.

Protecting Operators

To protect operators and others in the neighbourhood from the danger of potentially explosive plant, the Chief Inspector recommends putting the plant outside any occupied room, in a place where it is not likely to injure anyone if it does explode. A case is reported of a firm installing a plant to manufacture refrigerators of the absorption type, based on evaporating liquid ammonia in an atmosphere of hydrogen, which originally set aside a fairly large workroom for the handling of hydrogen. After some discussion, the firm reconsidered the scheme and decided to fix the plant to the outside of the factory wall and sheltered by only a small roof.

The controls were fitted inside the workroom and passed through the wall. Observation windows were placed in the wall and a cat-walk was built round the plant for the use of maintenance men. In normal circumstances a door prevents access to the cat-walk. The plant is therefore in the open air, well above ground level, separated from the workers by a substantial wall and inaccessible during use.

Thus the firm have provided a much safer plant without using a single safety device and have saved for themselves a large and useful area within the factory for other purposes.

* For the year 1958, Cmnd. 810, H.M.S.O., 1959, 5s. 6d.

621.926

COMMINUTION THEORY AND PRACTICE

A review of methods of selecting, operating and of estimating power requirements of size reduction equipment

by J. KELLEHER, M.Sc., A.R.I.C.

SUBSTANCES are comminuted to achieve certain results. The large surface area associated with finely divided materials facilitates their chemical treatment, roasting and oxidation. The rate of solution and even the solubility of a solute in a given solvent are known to increase with the fineness of the solute. The setting time of a cement falls rapidly with increasing fineness of grinding of raw material[1] whilst the tensile strength as measured at both seven and 28 days correspondingly increases.[2] The colour of pigments vary with fineness and to produce a specific shade of a given colour may require rigid control of the degree of comminution of the pigment. The shape of the particles may sometimes be important. The durability of paints is sometimes affected by the shapes of the component particles.[3] Crushed rock for ballast should be cubical not slabbed,[4] and cubical-shaped stone particles are more suitable than other shapes for road making. Sometimes products are required as either flakes or granules. Thus the objective of crushing and grinding is to give a product meeting the following specifications: (1) size range of component particles; and/or (2) specific surface; and/or (3) shape of component particles. The task of the chemical engineer is the selection rather than the design of the most suitable equipment for this purpose.

Selection of Size Reduction Equipment

A necessary preliminary to selection is a knowledge of the mode of action of the different types of equipment. Various types of force can be involved in size reduction, but four main types are commonly employed in conventional size reduction equipment, viz., compression, impact, attrition and shredding, the mode of action of each of which is illustrated in Table 1 by a typical example from everyday life and by a typical machine.* Two or three different types of force usually come into play in a single machine. Compression is generally limited to coarse crushing of hard materials. Impact and/or attrition may be used for softer, non-abrasive feeds. Combinations of compression and attrition, or impact and attrition, or impact and shredding can break any ordinary feed to almost any desired product size. Table 2 summarises the performance characteristics of a range of size reduction equipment.[4]

The type of machine selected must be appropriate to the physical characteristics of the material to be comminuted, the most important of which are:

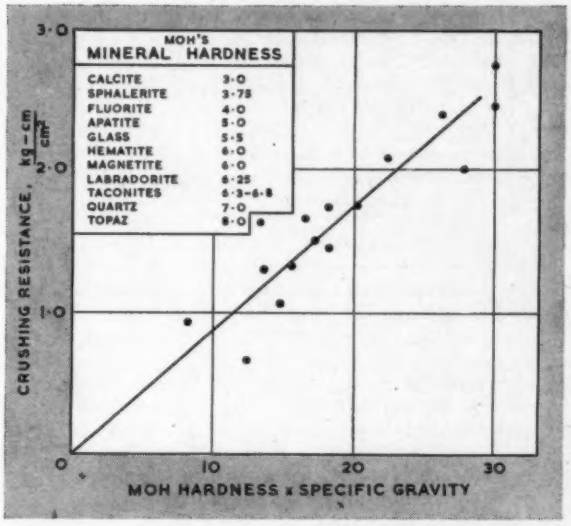


Fig. 1. An empirical correlation due to PIRET[9] *between the resistance of homogeneous materials to crushing and scratch hardness number.*

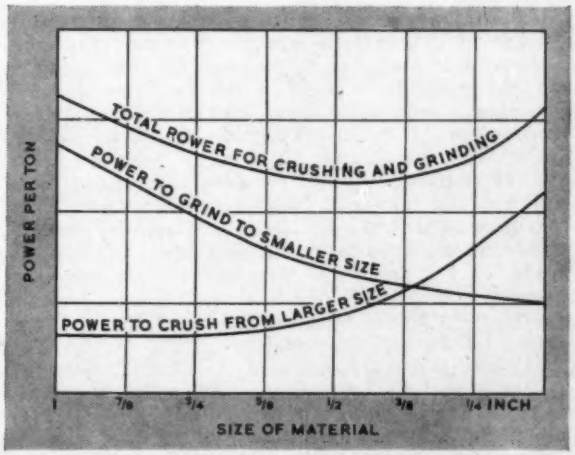


Fig. 2. Power consumption in crushing to and grinding from various sizes.[13]

* Methods of size reduction, such as emulsification, spraying and gas dispersion, are not considered in this article. Neither is explosive shattering (whereby a gas entrapped within the particles is caused to expand, suddenly shattering the material) since the commercial applications of this method are limited.[5]

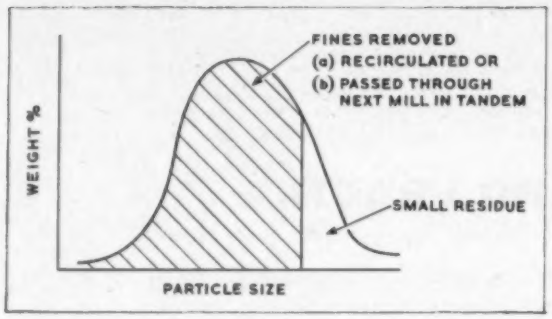


Fig. 3. Open-circuit grinding: typical size distribution curve.

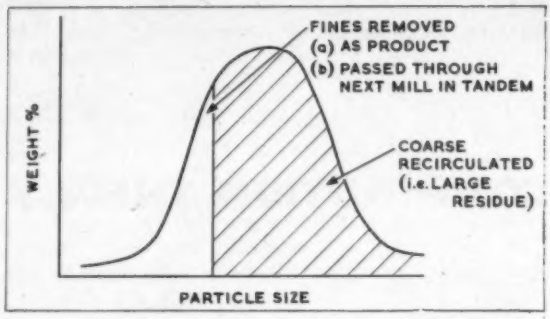


Fig. 4. Closed-circuit grinding: typical size distribution curve.

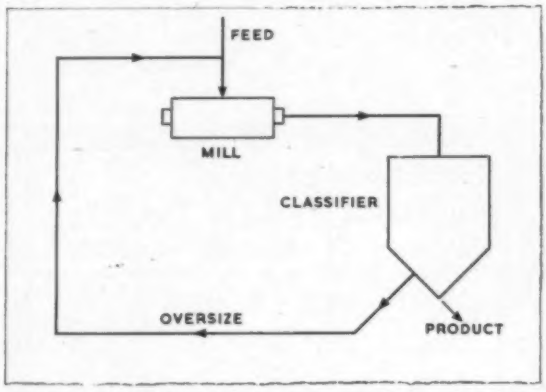


Fig. 5. Closed-circuit grinding system in which the feed contains few or no particles of the size desired in product.

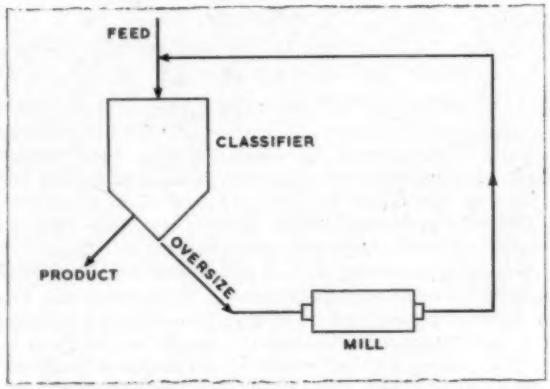


Fig. 6. Closed-circuit grinding system in which the feed contains an appreciable quantity of particles of the size required in the product.

(a) hardness;
(b) mechanical structure;
(c) moisture content; and
(d) temperature sensitivity and explosibility.

Two other factors are involved in the selection:

(e) the size of feed and product; and
(f) cost of equipment.

A detailed description of the significance of the separate factors follows.

(a) Hardness

It is difficult to define precisely the term hardness, and it has therefore been found expedient to express the degree of hardness of a material by its behaviour under a specified test procedure. A form of test used originally by mineralogists and lapidaries and later more rigidly formulated by MOHS[6] is the scratch hardness test. In this method the hardness of a material is defined by its position on a scale of materials (minerals) whereby each mineral will scratch the one below it on the scale but will not scratch the one above. Diamond, with a scratch hardness number (S.H.N.) of 10, is the hardest mineral, whilst talc with an S.H.N. of 1 is the softest. On this scale of reference, materials with an S.H.N. of 1 to 4 may be regarded as soft and those with an S.H.N. of 5 to 10 as hard. The groupings shown in Table 3 are thus obtained.[7]

The work of TABOR, KNOOP *et al.*, TAYLOR and WINCHELL[8] has shown that the S.H.N. is intimately related to the indentation hardness as measured by the force in kg/mm^2 required to press a specially designed indenter into the surface of a material under defined conditions. Thus the S.H.N. is linearly related to the log of the indentation hardness, both criteria being fundamentally related to the plastic properties of the materials concerned. PIRET[9] has shown that for homogeneous brittle materials the resistance to crushing expressed as total new surface produced per unit input of energy is linearly related to the S.H.N. This is shown in Fig. 1. The density factor in the abscissa does not have a large effect on the relationship, except to narrow somewhat the scatter of points.

The hardness of a material to be comminuted will therefore demand a mill of adequate size and structurally designed to ensure the required crushing action. It is also necessary to ensure, particularly with very hard materials having a concomitant high degree of abrasiveness, that the mill has a minimum of wearing parts, such as bearings, and these should also have appropriate protection from dust. Highly abrasive feeds require slow-moving equipment to avoid excessive wear, although sometimes it is economical to sacrifice one replaceable part in a higher speed unit for overall economy.[4]

(b) Mechanical Structure

In this context, the structural characteristics of materials which make them resistant to size reduction are considered. Compression is virtually useless for fibrous materials which require a shredding operation, although it has been reported that, if subjected to a precompression under high pressure, certain fibrous materials, such as derris root, become brittle and therefore more grindable.[10]

Waxy and plastic substances are also very difficult to reduce to a fine state, although they fall within the category of soft substances. Mechanical improvements in size reduction equipment for this purpose have not been very

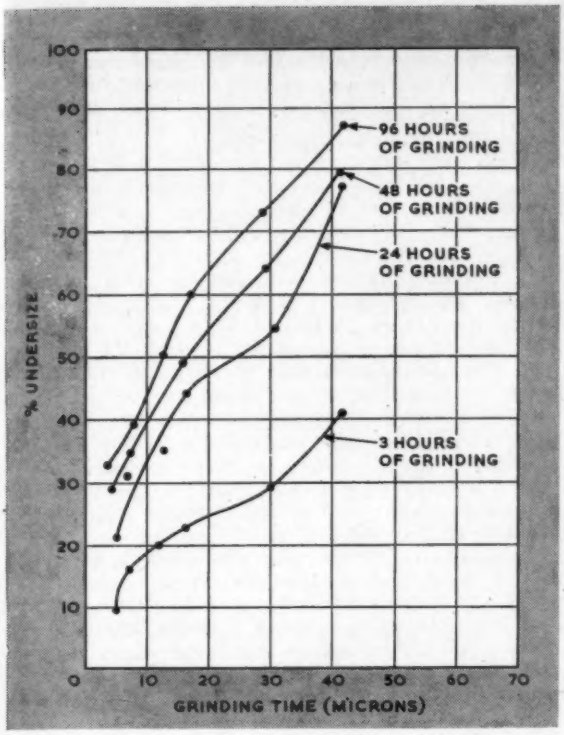


Fig. 7. Results obtained from the ball mill grinding of icing sugar in cocoa nut butter.

TABLE 1—Forces Involved in Size Reduction

Type of force	*Everyday example*	*Typical machine*
Compression	Cracking of nut with a nut cracker	Jaw crusher or gyratory crushers
Impact	Striking of stone with a hammer	Hammer mill and impactors
Attrition	Sharpening a knife on an emery wheel	Rod mills and ball mills
Shredding	Planing of wood with a spoke shave	Cutters and shredders. Squirrel cage disintegrators.

successful, but of recent years grinders chilled with liquid nitrogen have been successfully used to pulverise tough plastics, lard, beeswax and other difficult or heat-sensitive materials at temperatures well below –100°F.[4]

(c) Moisture Content

In the selection of size reduction equipment, and in particular the auxiliary equipment to be used with it, the moisture content of the material is of considerable importance. It is obvious that materials which are dry and free flowing require different treatment from materials which are pasty, and pasty materials again require different treatment from sludges and slurries. In general, pasty materials have more than 4 to 5% moisture, but the degree of pastiness of fine materials is in general greater than that of coarse materials of the same moisture content. Substantial increase of moisture content renders a material more fluid, and at about a level of 50% the moisture may have an advantageous effect in promoting free crushing by washing and transporting the finely ground product through the milling unit to the next unit in the processing sequence. Where a dry product is received in a fairly coarse form and subsequent processing requires a slurry or sludge, it is often convenient to prepare the slurry or sludge in the grinding equipment with the advantage mentioned. In choosing between wet and dry grinding, the relative advantages of both systems should be appreciated. Wet grinding has the following advantages:

(a) the power consumption per ton of product is lower;
(b) a higher capacity per cu. ft of mill volume is obtained;
(c) it permits the use of wet screening or classification where it is desirable to obtain strict control of product size;
(d) it permits the use of simple handling methods such as pumps, pipes and launders;
(e) it eliminates the dust problem; and
(f) it often enables finer adjustments to be made in the grinding equipment when handling difficult materials.

Dry grinding (or grinding in which the moisture content is maintained at a minimum so that the material does not stick) has the advantages that:

(a) it causes a lower wear rate on grinding media and mill liners; and
(b) it results in a higher percentage of fines in the product, which in many cases may be desirable.[11]

The choice between wet and dry grinding depends ulti-

TABLE 2—Performance or Typical Size Reduction Equipment[4]

Type	*Action*	*Typical feed sizes*	*Typical product sizes*	*Capacity range tons/hr*	*Power required hp.-hr/ton*	*Used extensively for*	*Not usually used for*	*Remarks*
Jaw crushers	Compression	6–72 in.	1–11 in.	10–1000	0.3–1	Medium and hard rock	Soft, sticky materials	
Gyratories								
Large	Compression	6–72 in.	1–11 in.	35–3500	0.2–0.7	Medium and hard rock	Soft, sticky materials	
Small	Compression and impact	1–10 in.	¼–1¼ in.	10–600	0.5–3			
Roll crushers								
Smooth	Compression	¼–3 in.	¼–¾ in.	3–150	1–1½	Medium and tough, abrasive feeds	Large slippery lumps	Gives few fines; reduction ratio 4:1
Toothed	Shear, attrition, impact	3–20 in.	2–8 in.	5–1000	0.2–0.5	Friable feeds	Hard rock	Gives few fines; reduction ratio up to 8:1
Revolving mills								
Rod	Attrition (impact)	¼–1 in.	4–28 mesh	3–120	0.5–4	Pregrinding abrasive feeds	Fine grinding	
Ball, pebble, tube, compartment	Attrition and impact	30 mesh to 1 in.	20 to –200 mesh	0.5–75	10–20	Fine grinding abrasive feeds	Soft materials	Often used for mixing and blending
Hammer mills								
Impactors	Impact	10 mesh to 10 in.	48 mesh to ¼ in.	0.2–600	0.5–10	Abrasive feeds	Fine grinding	Handles damp feeds
Swing hammer mills, hogs	Impact and attrition	20 mesh to 40 in.	–325 mesh to 2 in.	0.05–400	1–200	Almost any non-abrasive material	Abrasive feeds	Coarse to ultrafine reduction
Cutters and shredders	Cutting	1–12 in.; wide sheets	4–100 mesh	0.1–10	10–25	Soft lumps; fibrous, rubber, plastic materials	Hard materials	
Ring roll mills, bowl mills	Rolling compression	20 mesh to 1 in.	–325 to 20 mesh	0.02–20	5–200	Soft to fairly hard materials	Abrasive feeds	Large amount of fines produced; mill usually air swept
Attrition mills	Attrition	⅛ to 1 in.	–200 to 20 mesh	0.2–5	15–200	Soft, fibrous materials	Hard, abrasive feeds	
Fluid energy mills	Impact (attrition)	100 mesh to ¼ in.	1–30 microns	0.1–10	*	Moderately hard, friable feeds	Soft, sticky materials	Ultrafine reduction

* 1–4 lb. of steam or 6–9 lb. compressed air per lb. of product.

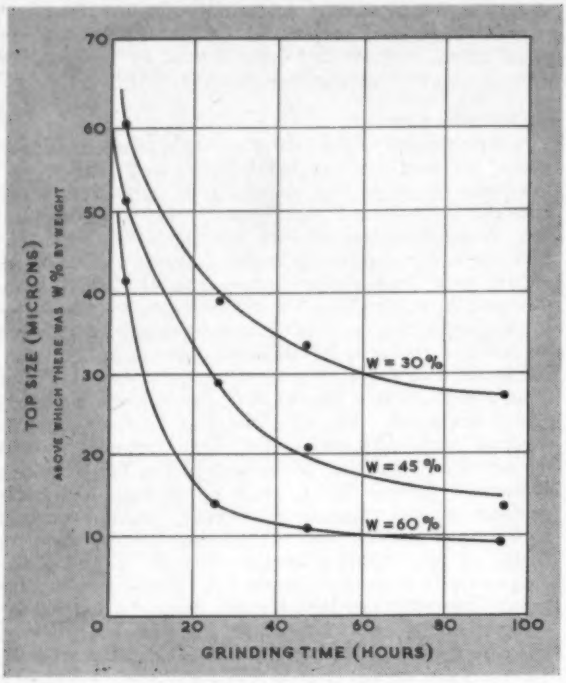


Fig. 8. Data of Fig. 7 plotted as "Top Sizes" against grinding times.

mately on the use of the product and its subsequent processing. One disadvantage of wet grinding in this context is that it causes a flocculation of particles smaller than 10 microns. Dispersing agents, such as silicates, phosphates and alkyl aryl sulphuric acids, are sometimes employed to offset this undesirable feature. If water (or other liquids used in wet grinding) are conducive to the chemical change of the material, then dry grinding is imperative. Grinding aids, such as oleic acid for zinc blende, and colloidal carbon and aluminium stearate for cement clinker, are sometimes useful adjuncts to dry grinding.[7]

(d) Temperature Sensitivity and Explosivity[10]

The heat generated during crushing and grinding, particularly where power requirements are high, may lead to decomposition or undesirable changes in the product. For example, the heat generated with tough plastic materials may cause the softening point to be exceeded, thereby causing a temporary shut-down of plant. Many of the newer insecticides are heat sensitive and require fine grinding.

In such cases the materials may be chilled prior to grinding either in storage or, if practicable, in a chilled atmosphere in transit to the unit or through the mixing of crushed dry ice with the material before grinding. It is also advantageous to pipe chilled air into the grinding chamber. For example, stearic acid is successfully ground to a 100-mesh product with dry ice and conditioned air.

It is also possible to use liquid nitrogen, for chilling the grinders, with heat-sensitive materials. In this case the material of construction of the mill should be stainless steel or other cold resisting alloy. Cast iron and steel should not be used, since these become brittle at low temperatures.

Many organic materials of a combustible character and metallic powders are subject to an explosion hazard during grinding. To offset this and also to prevent undesirable oxidative changes in a particularly sensitive material the whole operation may be carried out in an inert atmosphere of nitrogen or carbon dioxide. The solids may, moreover, be retained in this atmosphere for part of the subsequent processing. Washed flue gas is a valuable and economic inert atmosphere. In addition to inert atmospheres, more elaborate explosion-suppression equipment and precautionary measures may be necessary or desirable.

(e) Particle Size of Feed and Product

At the outset the maximum size of the particles constituting the feed should be clearly ascertained so that the machine selected will be adequate. Table 2 shows the extremes of feed sizes which can be handled by the range of equipment available, i.e., from 72 in. (coarse crushers) to 100 mesh (fluid energy mills). The table also shows the product sizes which can be obtained, ranging from 11 in. (coarse crushers) to 30 microns (fluid energy mills). The ratio of feed size to product size is called the reduction ratio. Thus the reduction ratio of coarse crushers is $72/11 = 6.5:1$ approx., and of fluid energy mills $423:1$ on the basis of the above feed and product size particles. Some times the reduction ratio is expressed in terms of the sizes of particles of feed and product below (or above) which there is a certain percentage by weight, but is more often represented as the ratio of the average size of feed to average size of product.

The size range of the product also influences the choice of mill. Some types, such as ring roll mills, give a huge amount of fines; others, such as crushing rolls, give few fines and some, such as slitters and special cutters, give no fines at all. The method of mill operation, i.e., whether use is made of open or closed circuit grinding, is also important. This aspect is discussed under methods of mill operation.

Finally, there may be definite specifications as to surface or particle size distribution of the product. Normally manufacturers will specify a mill to produce a product from a given feed having a limited size specification such as "85% of the particles of which will pass through a No. 60 mesh sieve". Two specifications, however, are a minimum necessary to specify the size distribution, for example, "85% through a No. 60 sieve and 5% through a No. 325 sieve". These correspond to two points on a cumulative per cent undersize distribution curve[7] (cf. Fig. 10).

(f) Cost

The two most significant items in the evaluation of cost are power requirements and maintenance. Because nearly all size reduction equipment is continuous and often handles large tonnage, operating labour costs are usually small.[4] Maintenance costs consist mainly of the charge for replacing the grinding surfaces and the cost of labour required for the replacement. The tonnage is the decisive factor in balancing fixed charges against operating costs. If the tonnage is high, it will, in general, be economical to invest fairly heavily in the cost of installation, thereby cutting down on power requirements. It should be noted that the installation and operation of size reduction equipment requires the process to be considered in its entirety, including the auxiliary equipment. The pretreatment of the feed and accessories, such as screens and classifiers, are often vitally important. For example, in large plants, where intensive size reduction is required, for the sake of efficiency it may be necessary to grind in successive steps or stages in different mills in closed circuit.

In certain borderline cases a decision may have to be made between crushing and grinding equipment. This may happen when the size of feed and the required size of product seem equally appropriate to crushing or grinding. Crushers reduce large to medium size particles, whilst grinders are best adapted to reduction of intermediate size particles and less to finer particles. In a borderline case a decision would have to be made whether to install a coarse grinder or a fine crusher, or at what point in a series of

size reduction operations it would be expedient to change from crushing to grinding. As the degree of size reduction required with a crushing operation increases, so does the power requirements, while as the feed size to a grinding operation increases so also does the power requirements. This means that when a machine is unsuited for the duty it is made to perform, the process will involve a wastage of power commensurate with the degree of unsuitability. A plot of power requirements when crushing to different sizes and when handling coarser feed sizes in grinding operations is given in Fig. 2. Combination of the curves as shown indicates that the optimum size for changeover from crushing to grinding is ½ in., which is characteristic of a large variety of materials. A coarser grinding mill feed is possible with soft materials, such as gypsum, while it is advantageous to use a finer mill feed with harder materials such as quartz and carborundum.[13]

Methods of Mill Operation[11, 14, 15]

Generally speaking, whether mills are operated batchwise or continuously there are two methods of feeding:

(a) choke feeding; and
(b) free crushing.

In choke feeding the mill is heavily loaded to increase throughput. In this method partially crushed particles interfere with the crushing of the larger lumps of feed. In free crushing the feed rate is adjusted so that the crushing elements are able to work on each particle independently, as if no other particle was present. Under ideal conditions this involves the removal of each particle from between the grinding surfaces as soon as it has reached the required dimension. Free crushing avoids the wastage of power in reducing particles beyond the limit required, but it may sometimes be uneconomical if sacrifice of throughput is involved. In choke feeding, power is wasted in the interest of throughput and a whole range of differently sized particles travels through the crushing surfaces. Whether this is a disadvantage or not depends ultimately on the size characteristic specification of the product.

In deciding upon the method of mill operation before installing a plant, a choice may also have to be made between:

(a) open-circuit grinding; or
(b) closed-circuit grinding.

In continuous open-circuit grinding the product specification is achieved by passing the feed through the first mill, separating the fine material, and passing this to the next unit in the series. Alternatively, if there is but one mill, as in batch operation, the fines are removed and recirculated and the oversize rejected. The portion passed to the next mill (in continuous operation) or recirculated (in batch operation) is shown by the shaded area of the size distribution curve of Fig. 3. In open-circuit grinding it is not always possible or expedient to avoid choke feeding, and hence there is an inevitable wastage of power. The advantage of the method is that the equipment required is simple, and hence relatively inexpensive to use where tonnages are low.

Closed-circuit grinding operates on a once-through basis without recirculation of product. The acceptable material is separated and the oversize portion is returned to the mill for further reduction; i.e., the entire output of the mill goes to a size separation unit or classifier where the product is separated from oversize material and the latter is returned for regrinding. This increases mill capacity, and, since power consumption does not increase rapidly until finer sizes are produced, it follows that closed-circuit grinding, though useful for any crusher, has its most useful applications to those machines that normally make a finer product. Fig. 4 shows the oversize portion (shaded) in closed-circuit grinding.

TABLE 3—Scratch Hardness Numbers (S.H.N.) of Minerals[2]

Soft Materials	*S.H.N.*	*Hard Materials*	*S.H.N.*
Talc, dried filter-press cakes, waxes, soapstone and aggregated salt crystals	1	Apatite, hard phosphate, hard limestone, chromite and bauxite	5
Gypsum, rock salt, crystalline salts in general, graphite and soft coal	2	Feldspar ilmenite, orthoclase and hornblendes	6
		Quartz and granite	7
		Topaz	8
		Corundum sapphire and emery	9
		Diamond	10
Calcite, marble, soft limestone, barytes chalk and brimstone	3		
Fluorite, soft phosphate, magnesite and limestone	4		

Figs. 5 and 6 show two types of closed-circuit system. The first system (Fig. 5) is a simple closed circuit which is used when the feed contains few or no particles of the size desired in the product—both the feed and the oversize pass directly to the mill for regrinding. In the second type (Fig. 6) the feed is a product from a previous stage of grinding (possibly in open circuit), and therefore contains a considerable amount of fine particles. The feed is accordingly conveyed directly to the classifier, its fines separated and the oversize then conveyed to the mill; the product from the mill is then conveyed to the classifier as shown. By either system of closed-circuit grinding the character of the final product size distribution may be controlled by controlling the volume of fluid to the system. When air (in an air classification system) is moved at high speed through the mill, for example, a closely sized product may be obtained, since the particles of the size desired are removed as soon as they are formed. The closed-circuit operation combines free crushing with large capacity. The advantages of closed-circuit grinding are:

(a) low energy consumption combined with large capacity;
(b) particle size distribution may be controlled within desired size limits; and
(c) less wear on mill liners.

Its disadvantages are:

(a) high first cost; and
(b) complication due to the large grinding volume.

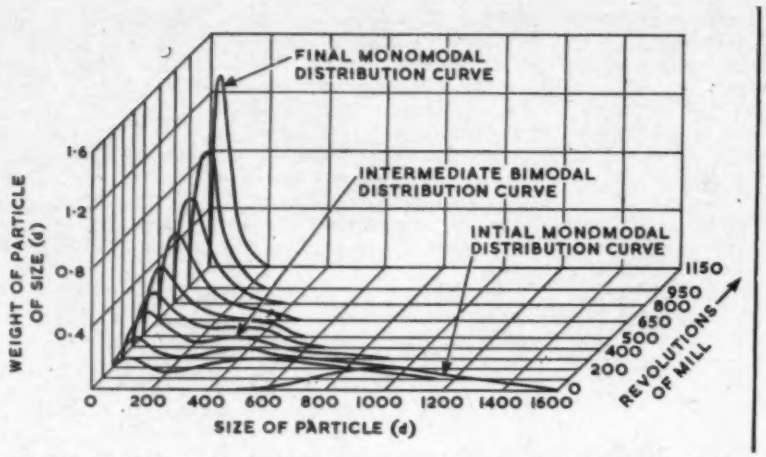
Certain mills have classifiers integral with the mill itself; for example, the Raymond mill and fluid energy mills.

Theory of Size Reduction

In 1942 in an investigation of ball mill grinding with Ottawa sand, SCHWEYER[16] showed by means of the "Top Size" criterion that it was possible to determine the limiting effectiveness of a given machine for size reduction. The top size may be defined as the particle size above which there is W % of material by weight. If cumulative per cent undersize distribution curves of the material for various stages of grinding are available, then the particle size corresponding to W may be read off and plotted against time or other criterion (such as number of ball mill revolutions) used to denote these stages of grinding.

In a study of the breakdown of icing sugar particles in a cocoa butter medium during ball mill grinding, KELLEHER[17] obtained the curves shown in Fig. 7. By choosing W as 30, 45 and 60% by weight and plotting the corresponding top sizes against the grinding time the curves in Fig. 8 were obtained. The significance of these curves is that they indicate the limit of 95 hr, beyond which further grinding would be ineffective and therefore uneconomical. The curves also indicate that each value of W chosen to define the top size of particle was equally effective in indicating the economical limit of grinding.

SCHWEYER'S investigation was similar, but took account of the effect of the viscosity of the grinding medium (a glycerol-water solution) on the rate of decrease of top size with grinding. The viscosity was varied by varying



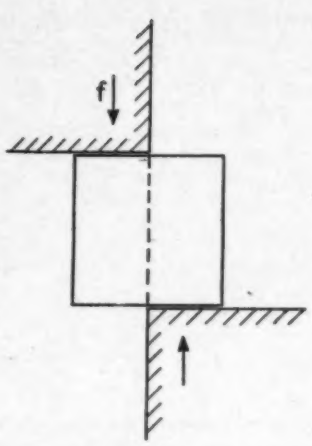


Fig. 10 (*left*). *Variation of size distribution with progress of grinding.*[18] (*Courtesy Institution of Mechanical Engineers.*)
Fig. 11. *Diagram of cube of homogeneous material subjected to deforming stress.*

the proportion of glycerol to water, which gave a range of grinding media from 1 to 400 centipoises; a dry grinding experiment was also performed, i.e., with air as grinding medium. The top size was defined by $W = 10\%$ and the grinding unit was a porcelain pebble mill. The stages of grinding were represented by the number of revolutions in thousands. SCHWEYER produced curves to show that the top size decreases rapidly at the start and then decreases at a diminishing rate to approach, finally, a limiting size. Although it was not evident that there was any relationship between limiting top size and viscosity, it was clear that the limit of grinding was attained more rapidly at the lower viscosities. SCHWEYER concluded that the more viscous the fluid the more it tends to

(a) absorb the shock of impact when the balls fall; and
(b) lubricate the action of the balls rolling over one another, reducing thereby the effect of attrition in size reduction.

The foregoing shows that for a given machine taking a given size of feed there is a limit of size reduction attainable beyond which further grinding is ineffective. It is now pertinent to consider the changes in size distribution which take place as grinding progresses in a given machine.

Assuming the material fed to the mill has a monomodal size distribution, then as grinding proceeds it develops a bimodal size distribution as shown in Fig. 9. The primary (or transient) component gradually decreases in weight as grinding progresses, whilst the secondary (or persistent) component increases in weight. This reduction in weight is accompanied by a decrease in the modal size of the transient component and is caused by the preferential breakdown of larger particles. The modal size of the secondary component remains constant. With further grinding the primary component tends to be eliminated and the idealised conditions illustrated in Fig. 9 might be summarised thus:

Initial: Monomodal Distribution
Intermediate: Bimodal Distribution
Final: Monomodal Distribution

If the material corresponding to the final stage is now transferred to a second machine for finer size reduction, then this size reduction process will be repeated. The persistent mode of the former size reduction operation will now become the transient mode in the new operation and a new persistent mode corresponding to a lower particle size will result.[18] This description is intended to represent an idealised operation, since any given machine might not in practice bring about the changes from initial to final represented above; several machines might, in fact, be required.

The shape of the distribution curves in Fig. 9 illustrate the difficulty of providing an overall equation to express size distributions as obtained by crushing and grinding. A number of equations have been proposed, none of which has been found satisfactory to cover all cases.[19] This problem may not prove wholly intractable, since there is some evidence that a definite fracture pattern persists throughout all crushing and grinding processes.[20]

Power Consumption During Crushing and Grinding

The most important problem in size reduction is the establishment of a theory by means of which the power consumption in crushing and grinding can be predicted. A consideration of the classical theories of RITTINGER and KICK and the modern theories of BOND and HOLMES serves to bring into perspective the difficulties involved as well as indicating a basis for future work. These theories are known as the first, second, third and fourth theories of comminution respectively.

First Theory of Comminution

Rittinger's Law. The earliest theory, that of RITTINGER,[21] states that the energy (E) required for grinding a given material is proportional to the area of new surface formed, thus:

$$E = C\,(S'_w - S_w) \qquad \ldots . (1)$$

where S'_w and S_w are the surfaces per unit weight of material (i.e., the specific surfaces) after and before size reduction respectively. The constant C is peculiar to the grinding unit employed and represents the energy required to enlarge the surface of unit weight of a given material by one unit of area.

Equation (1) can be expressed in another way. Assume that unit volume of a particulate material of mean size D is ground to a powder, the particles of which have a mean size d. Since the volume of a particle is proportional to the cube of its linear dimension, then:

volume of a feed particle of mean size $= kD^3$

where k is a factor termed the volume coefficient and which takes account of the shape of the particle. Hence the number of the particles in unit volume of feed $= \dfrac{1}{kD^3}$.

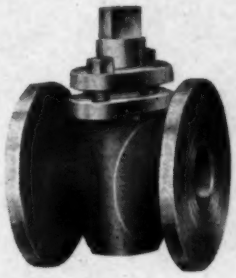
Now the surface area of a particle is proportional to the square of its linear dimension and thus:

surface area of an individual feed particle of mean size

HINDLE

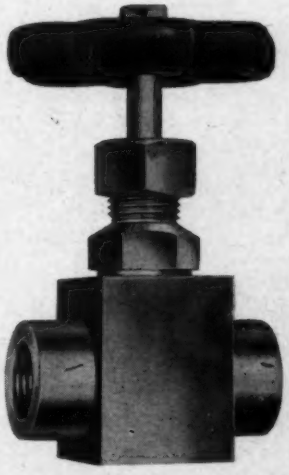
STAINLESS STEEL VALVES, COCKS AND PIPELINE FITTINGS

801
GLAND PACKED COCK



118
SOLID WEDGE GATE VALVE
Outside screw with bridge and pillars : non-rising handwheel

230
BAR STOCK GLOBE VALVE
Inside screw



740
LIQUID LEVEL GAUGE

Illustrated are a few examples of HINDLE Valves, Cocks and Pipe Line Fittings. In particular we cater for those who have a special valve problem, whether one of corrosion or of a positive sealing requirement. In addition to the standard range of 18/8 and 18/8/3 Stainless Steel, HINDLE Valves may be supplied in other grades of Stainless Steel, Monel or Nickel. For details of complete range please ask for HINDLE Catalogue.

406 CHECK VALVE
Swing flap type: screwed cover

JOSHUA HINDLE & SONS LIMITED

HINDLE HOUSE, LEEDS, 1 Telephone: Leeds 30567 (4 lines)
London: 157 Prince's Gardens, Acton, W.1 Telephone ACOrn 2471

$$= fD^2$$

where f is the surface coefficient which also takes account of the shape of the particle. Hence the total surface area of feed particles per unit volume $= \frac{fD^2}{kD^3} = \frac{f}{k} \cdot \frac{1}{D}$, i.e., total surface per unit weight (or specific surface S_w)

$$= \frac{f}{\sigma k} \cdot \frac{1}{D} = K\frac{1}{D}$$

where σ is the density of the material. Thus for spheres $K = 6/\sigma$. Similarly, the specific surface of the product particles $S'_w = K\frac{1}{d}$ assuming the product has the same factor K accounting for the shape and density of the particle. Thus Equation (1) may be written:

$$E = C\left(\frac{1}{d} - \frac{1}{D}\right) \quad \ldots.(2)$$

The only difference being that the constant C now includes the constant $K\ (= f/\sigma k)$.

In the evaluation of power requirements the following method may be used to determine the mean size of particle in a material in which there is a variation in particle size. If W is the total weight of material of mean size d and if $d_1, d_2, d_3, \ldots d_n$ are the particle sizes in the weight fractions $w_1, w_2, w_3, \ldots w_n$ respectively, then assuming the particles are cubes:

$$\text{surface area of particles} = \frac{W}{\sigma d} = \frac{w_1}{\sigma d_1} + \frac{w_2}{\sigma d_2} + \frac{w_3}{\sigma d_3} \cdots \frac{w_n}{\sigma d_n} \quad \ldots.(3)$$

$$\therefore \frac{1}{d} = \frac{1}{W}\left(\frac{w_1}{d_1} + \frac{w_2}{d_2} + \frac{w_3}{d_3} \cdots \frac{w_n}{d_n}\right) \quad \ldots.(4)$$

writing $\triangle W$ for $w_1, w_2, w_3, \ldots w_n$ and d_x for $d_1, d_2, d_3, \ldots d_n$ then Equation (4) becomes:

$$\frac{1}{d} = \frac{1}{W}\sum_{0}^{W}\frac{\triangle W}{d_x} \quad \ldots.(5)$$

Equations (4) or (5) can be used for determining the reciprocal of both the mean size of feed and the mean size of product particles in the equation regardless of departure from a cubical shape. Thus it may be assumed that both feed and product particles in the aggregate have the same shape and that the variation of shape will be more or less the same for all size ranges covered by the weight fractions $w_1, w_2, w_3, \ldots w_n$.

Equations (4) and (5) are particularly adapted for determining power requirements by RITTINGER'S Equation (2), when sieving and/or elutriation methods can be applied to the size analysis of the feed and product. For finer materials (i.e., in the sub-sieve range) use is made of Equation (1) by determining the specific surfaces directly by nitrogen adsorption or more usually, and perhaps more appropriately, by permeability methods. Sometimes sieving or elutriation methods may be combined with permeability methods. In this case the overall surface areas may be used in Equation (1) by a summation of the surface area of the fraction determined by the permeability method and that calculated by Equation (3). Alternatively, a mean size of the feed (or product) particles constituting the sieve range and a mean size of feed particles (or product) constituting the sub-sieve range might be separately determined and an overall mean calculated. The mean particle size d in the sub-sieve range is calculated from the specific surface S_w as follows.

$$\text{Total surface per unit weight } S_w = \frac{1}{\sigma} \cdot \frac{f}{k} \cdot \frac{1}{d} = \frac{K}{d}$$

and hence

$$d = \frac{K}{S_w} \quad \ldots.(6)$$

(To be continued)

Warren Spring Laboratory

"HERE we have a laboratory which does not merely do experiments. It is itself an experiment." With these words, LORD HAILSHAM, as Lord President of the Council, formally opened the latest D.S.I.R. laboratory at Warren Spring. In some ways the new laboratory takes the place of the old Fuel Research Station, but it will have no limits imposed by its terms of reference. It was named after the site; no subject is quoted in its title to avoid any suggestion of restricting its field of activity. It will therefore be free to undertake any research within its field of knowledge for which it has the necessary resources. The Station consists of a main three-storey laboratory building and three pilot-scale buildings each 90 ft long by 55 ft wide by 37 ft 6 in. maximum height. There are also workshops and other services. All the buildings and facilities are capable of being extended by at least 100%. At present, the programme consists of work on atmospheric pollution and on the following subjects.

Synthesis of oils and chemicals from carbon monoxide and hydrogen is being investigated as part of a project to develop an economic process for producing oil from coal. The process is based on complete gasification of coal to yield a mixture of carbon monoxide and hydrogen followed by catalytic conversion of the gas mixture. Only the second stage—using the slurry technique development of the Fischer-Tropsch process—is under study at Warren Spring. The gas mixture is passed through a suspension of powdered catalyst in molten wax at temperatures in the range 250°C to 300°C at pressures between 5 and 30 atmospheres. Objectives of the programme are improvement of the iron catalyst, selecting optimum operating conditions and gaining the data necessary to design a full-scale reaction vessel. Synthesis gas is produced on the site at a rate of 4500 std. cu. ft an hr in a standard water-gas generator with arrangements for feeding carbon dioxide with the steam so as to vary the hydrogen/carbon monoxide ratio between 1.15 and 0.6.

It is expected that for some time much of the effort of the Mineral Processing Division will be engaged on sponsored work on particular ores, but "it is hoped" to carry out basic studies of grinding in the presence of additives, of the kinetics of bubble attachments to mineral surfaces as in froth flotation and of the behaviour of mineral particles in a high-tension field.

The laboratories are equipped to handle most laboratory-scale mineral-dressing operations such as flotation, jigging, tabling, heavy-media separation, wet and dry magnetic separation, and high-voltage separation. In the hydrometallurgical field facilities are available for atmospheric and pressure leaching, for fluidised-bed roasting, chlorine metallurgy and solvent extraction.

One of the divisions, entitled "Chemical Engineering", has three functions:

(i) to carry out research on physical operations which play an important part both in processes which are under development in the laboratory and those in more general use in industry;

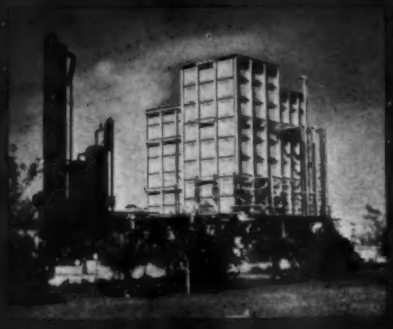
(ii) to undertake research in chemical engineering sponsored by industry or Government Depts.; and

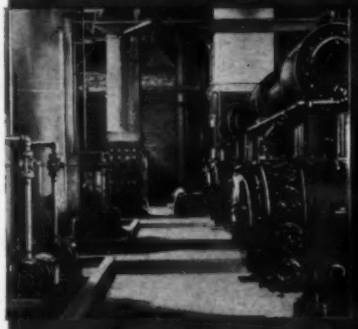
(iii) to accumulate basic data in chemical engineering.

After extensive consultation and after considering work in progress elsewhere, it was decided to concentrate on mass transfer. The five main lines of study are bubble dynamics on distillation plates, gas-liquid mass-transfer rates, fluid-mixing on distillation plates, gas absorption with chemical reaction, and drop-wise condensation promoters. The distillation projects will supplement those sponsored in other establishments by the A.B.C.M. and the B.C.P.M.A.

BCE 5874 for further information

CRYOGENICS





In the chemical industry

The products from applied cryogenics—the science of Low Temperature Processing—now being used commercially in the Chemical Industry include:

Oxygen · Nitrogen · Argon · Hydrogen · Acetylene · Ethylene · Ammonia · Carbon Monoxide

The technological research and engineering developments of Air Products are available to industry on an applied engineering basis. As builders of low temperature equipment for the chemical industry, Air Products has supplied the largest oxygen tonnage plant in Europe, the largest argon tonnage plant in Europe, and the largest ethylene tonnage plant in Europe. Air Products has also supplied the largest hydrogen plant in Europe, and the largest carbon monoxide plant in Europe. Through these and other achievements, Air Products has gained a unique experience in the chemical industry.

Air Products

AMERICAN LETTER

The Fifth World Petroleum Congress

DURING the first week in June, New York was host to the Fifth World Petroleum Congress, at which nearly 300 papers were presented. About 60 of these were devoted to geology and geophysics, while several more dealt with the latest electronic and other physical methods of prospecting for oil. One topic of conversation was the explosion method of hole sinking developed by the Russians. The Congress was supported by an exhibition in which over 200 organisations took part, including several well-known British and European companies. Exhibits could be broadly classified into three categories: oilfield equipment, refinery technology and instrumentation.

Oilfield Equipment

Among numerous devices designed to reduce the cost of hole sinking and to increase the yield of oil, one interesting feature was the use of the 500-hp Solar air-cooled gas turbine to drive a trailer-mounted 5500-ft rig. The light weight, mobility and potentially useful heat output of 5 million Btu/hr could materially offset the initial high price of $50,000 of the turbine, particularly for locations in cold weather zones. Another novel item was the Christiansen rubber-sleeved, core barrel which permits 100% recovery of loose formations and yields undisturbed cores. The German Pleuger deep-well oil pump also aroused interest, since this is a rodless, submersible electric pump using a piston-operated diaphragm working in a similar manner to a chemical slurry diaphragm pump.

Refinery Technology

Virtually all of the big names in refinery construction and operation were represented by blow-ups or models of their largest and latest achievements, including those in the petrochemical field. Not the least of these spectacular engineering feats is the Caltex 180-mile pipeline from Pernis in Holland to Godorf on the Rhine, near Bonn, Germany, which the Bechtel organisation is in the process of completing. Other noteworthy projects were the $200-million Tidewater automated refinery at Delaware (130,000 bbl of crude per day); a McKee atmospheric and vacuum crude distillation unit (140,000 bbl per day); the Hoechst HTP unit for the annual production of 100 million lb of acetylene and ethylene; and the 20,000 ton a year butyl rubber plant of the French Socabu company. The latter was built by the Italian C.T.I. Petroli concern to American process and engineering designs.

In contrast to the display of such enormous projects were many smaller exhibits of importance and interest to process and engineering designers. For example, it was encouraging to see a sample of ¼-in.-thick steel clad with Hastelloy "B" and which is now available in small lots from the Lukens Steel Co. This type of clad steel should find many future aplications in the chemical industry. Also cited as a new development by Hewitt-Robins was their Teflon-lined hose available in ¼-in. to 3 in. I.D. and usable between −100° and 400°F. Moulded Teflon bellows and flexible line couplings were displayed by the Resistoflex Corp., in sizes up to 6 in. Also in the corrosion-resistant field was a new diffusion-type coating for the protection of steel against sulphur attack in refinery service and against oxidation in furnace atmospheres. This is termed the Alumi-Spra coating, developed by the Chicago Metallizing Corp., and is based on the formation of a highly resistant film of aluminium oxide which is formed on a layer of aluminium applied to the base metal under closely controlled conditions.

The recent advances in cryogenics were typified by several units exhibited by such concerns as Air Products Inc., the Linde Co. and the North American Philips organisation (Norelco). The Philips Cryogenerators are small, packaged, low-temperature refrigeration units designed to operate down to −330°F, for use in gas liquefaction, separation and purification systems. Numerous industrial applications are predicted, such as the production of liquid or gaseous oxygen and nitrogen from air, metal treatment, shrink fitting and biological preservation. Operation of these units has been simplified to the push-button stage and a typical output is five quarts an hr of liquid air for the gas liquefier, which requires 10 hp and about 3½ gpm of cooling water.

Some further developments in cooling techniques, but of different scope and size, were illustrated by the Hudson Corp., which specialises in air-cooling systems for plant water. The Hudson "Combinaire" is a new type of cooling system in which ambient air is cooled to near wet-bulb temperature by a water section in the base of a tower and the cooled air is then used to reduce the plant water temperature in an air-cooled exchanger in the upper part of the tower. Among the advantages claimed are low water consumption, the avoidance of treatment for the cooling tower water, and no water losses from spray. During cold weather, the section cooling the ambient air is by-passed, so that no water is then used for operation.

Examples of the latest types of floating tank roof were shown by the Chicago Bridge, the Hammond Iron and the Wyatt companies. Several designs use an annular, rubber/canvas bag filled with liquid as the sealing ring. Other recent contributions by rubber technologists to the petroleum and heavy industries were exhibited by the Goodyear Co. One of these was the Terra Tire, which is a large, low-pressure load carrier available in sizes up to 60 in. dia. × 42 in. tread width and intended for work in soft or swampy areas. Another novel item was the Rolli-Tanker, which is a collapsible, synthetic rubber bag, mounted on a centre axle and intended to serve as a mobile, towed storage vessel for use on land or water. The 1800 gal. size costs $959 net. Still another storage container of unorthodox design was the collapsible rubber pillow, available in sizes up to 50,000 gal.

Instrumentation

Supplementing several computer-controlled refinery automation systems were several more modest new instruments, such as the General Electric gyro-integrating mass flowmeter. which measures gaseous or liquid flows by mass changes, independently of other variables. Maximum flow rates are presently 40,000 lb an hr for gases and 240,000 lb. an hr for liquids. Another unusual exhibit was the Ruska high-pressure viscosimeter of the falling-ball type, designed for operation up to 350°F and pressures up to 12,000 psig. One of the most interesting demonstrations was the use of a computer by the M. W. Kellog Co. to solve chemical engineering calculations on the spot. Already, the Texaco polymerisation unit at Port Arthur is reported to be under full computer control and other closed-loop systems are said to be on the way.

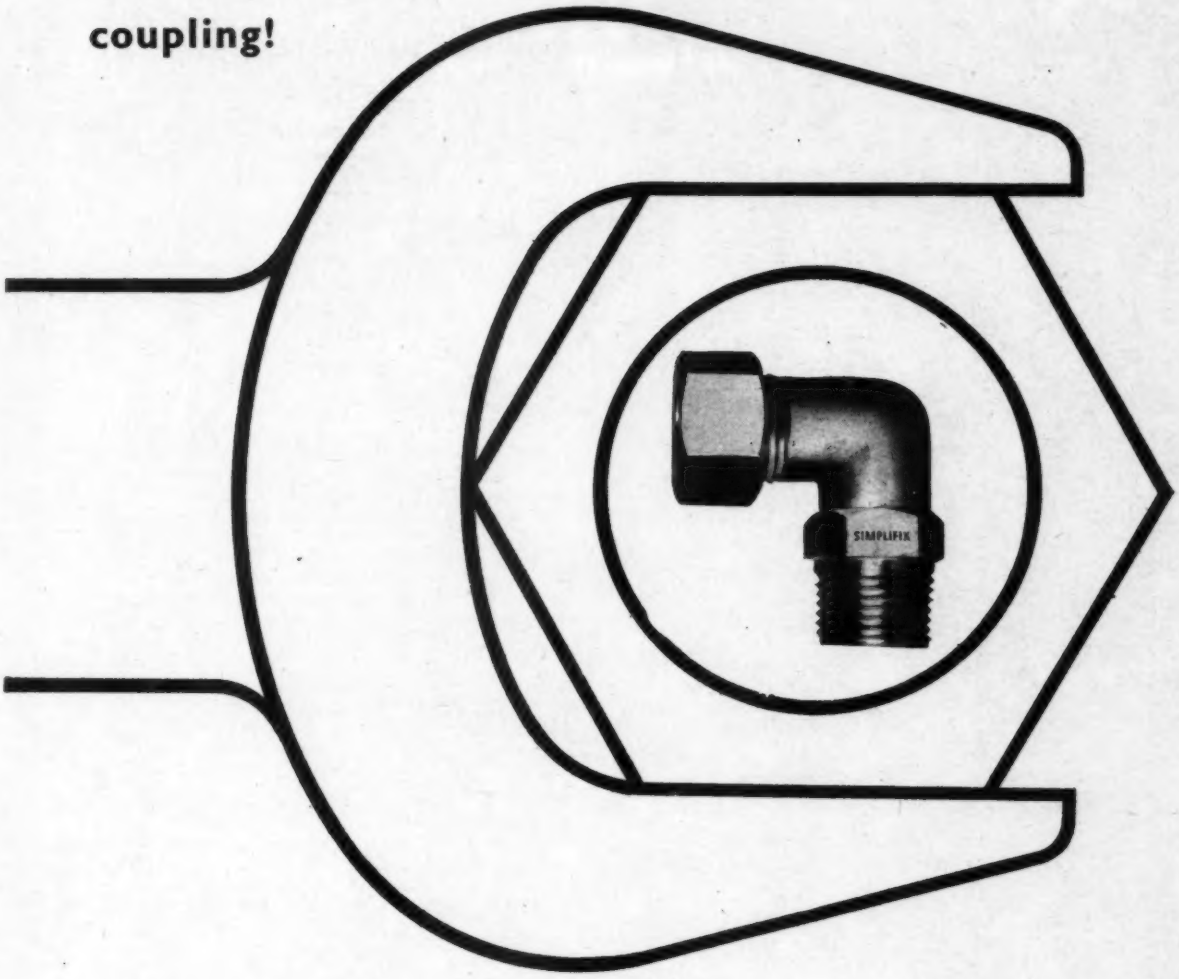
BCE 5875 for further information

So simple!

So surely SIMPLIFIX

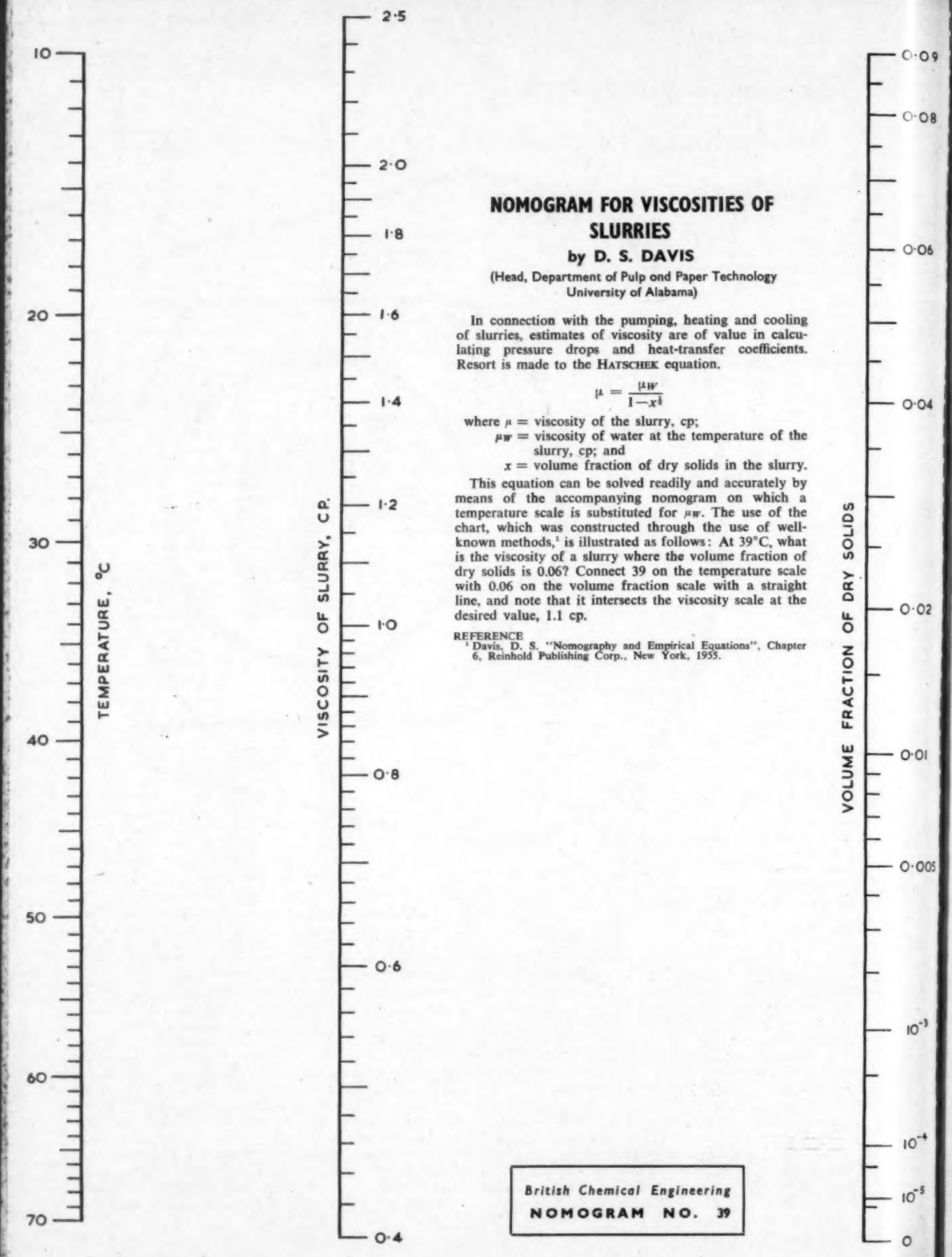
the foolproof

coupling!



Simplifix couplings form a perfect joint on almost
any kind of tubing including those with very thin walls.
All that is required is tightening with a spanner—
no special work is required on the tube and the anti-friction
washer prevents the tube twisting when the nut is tightened.
Simplifix couplings are suitable for all pipe line systems
up to 2" o.d. In a wide range of interchangeable standard fittings.
Non-standard fittings of all kinds can also be made to order.
Write for further information and fully illustrated catalogue.

SIMPLIFIX SIMPLIFIX COUPLINGS LTD · HARGRAVE RD · MAIDENHEAD · BERKS · TEL : MAIDENHEAD 5100
A member of the ALENCO Group of Companies



NOMOGRAM FOR VISCOSITIES OF SLURRIES

by D. S. DAVIS

(Head, Department of Pulp and Paper Technology
University of Alabama)

In connection with the pumping, heating and cooling of slurries, estimates of viscosity are of value in calculating pressure drops and heat-transfer coefficients. Resort is made to the HATSCHEK equation.

$$\mu = \frac{\mu_W}{1 - x^{\frac{1}{3}}}$$

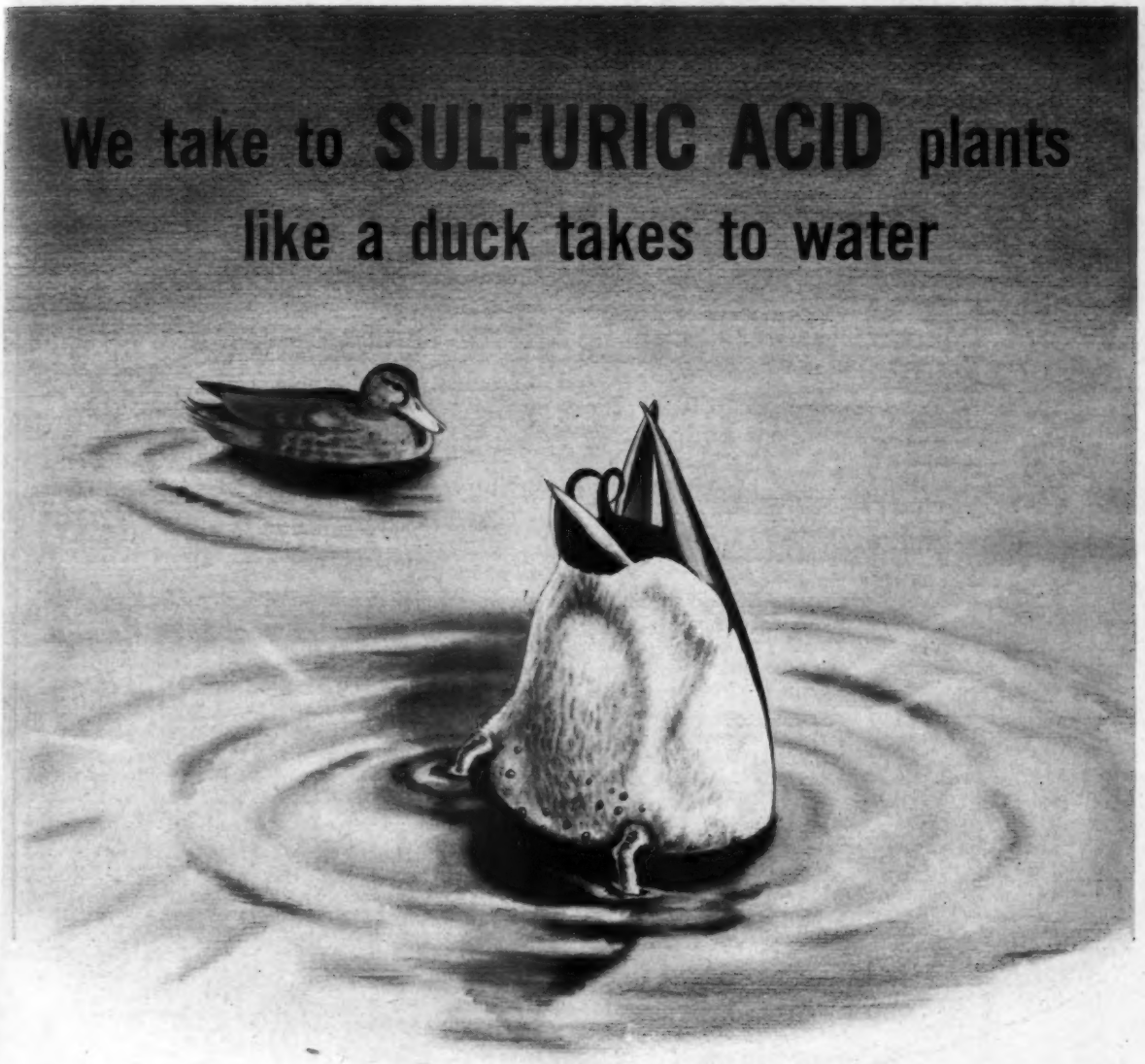
where μ = viscosity of the slurry, cp;
μ_W = viscosity of water at the temperature of the slurry, cp; and
x = volume fraction of dry solids in the slurry.

This equation can be solved readily and accurately by means of the accompanying nomogram on which a temperature scale is substituted for μ_W. The use of the chart, which was constructed through the use of well-known methods,[1] is illustrated as follows: At 39°C, what is the viscosity of a slurry where the volume fraction of dry solids is 0.06? Connect 39 on the temperature scale with 0.06 on the volume fraction scale with a straight line, and note that it intersects the viscosity scale at the desired value, 1.1 cp.

REFERENCE
[1] Davis, D. S. "Nomography and Empirical Equations", Chapter 6, Reinhold Publishing Corp., New York, 1955.

British Chemical Engineering
NOMOGRAM NO. 39

We take to SULFURIC ACID plants like a duck takes to water



CHEMICO, one of the largest chemical engineering organizations in the world, has grown up with Sulfuric Acid plants. We have built over 200 plants having an annual total output of over 7,000,000 tons which is approximately 30% of the world production from contact plants. We also manufacture and supply our own Sulfuric Acid catalyst. In the Sulfuric Acid field our experience is vast and worldwide, so when you think of Sulfuric Acid think of CHEMICO.

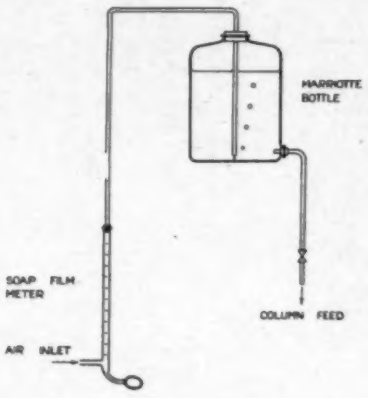
When you take the plunge into a new plant construction program you couldn't do better than get immersed in our new bulletin B.359

CHEMICO

CHEMICAL CONSTRUCTION (G.B.) LTD., 9 HENRIETTA PLACE, LONDON, W.1
Langham 6571

PROCESS ENGINEER'S NOTEBOOK

Flow-meter for Low Liquid Rates



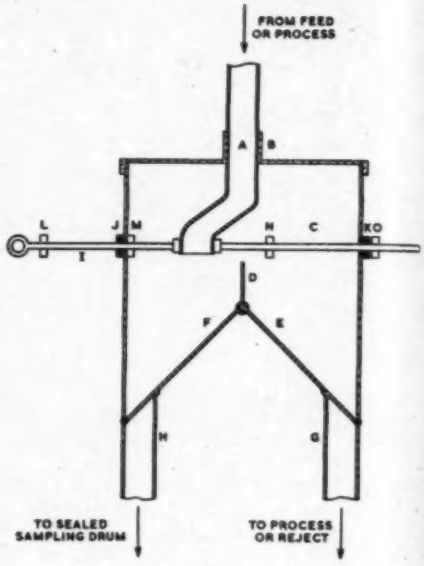
In a recent ion-exchange investigation, solutions were fed to the resin bed under a constant head, using the familiar Marriotte bottle. Rotameters, suitable for measuring in the flow-rate range required, were not readily available at the time. To avoid the rather tedious procedure of collecting effluent over timed intervals, a soap-bubble meter fabricated from a burette was used to measure the rate at which air flowed into the bottle to displace the feed liquor. This is illustrated in the accompanying diagram. The method proved so simple and reliable that it has been adopted for flow-rate measurement in all subsequent laboratory and small pilot-scale work on ion exchange and electrodialysis. It could also be conveniently used in work on gas absorption and liquid extraction. By appropriate sizing of the soap-film meter, flow-rates ranging from 1 to about 100 litres per hour can be measured.

The method is quite precise, provided air and solution are at the same temperature. Due allowance can be made for expansion of the air as it rises through the solution in the Marriotte bottle to the air-space above, by noting the liquid depth at the time of measurement. For example, if the depth of liquid is 1 ft, the measured rate should be increased by approximately 3%. In many applications a correction of this magnitude can be neglected.

A. M. Kennedy

Solids Transfer Valve

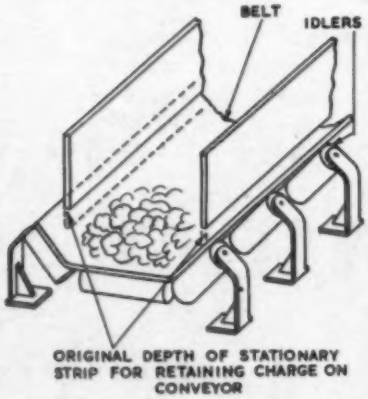
It is often necessary to take a sample from the main stream for quality tests or for checking the rate of solids flow in processes dealing with finely divided solids. The following device has been used as an alternative to the usual flap valves, which, if made dustproof, may jam in operation. Fine solid from the process flowed through flexible pipe (A) which was secured to the lid (B) of bunker (C). The chamber was divided centrally by plate (D) attached to sloping bases (F) and (E). One side led to exit pipe (H), which was used for obtaining the sample in a sealed drum; the other side was connected to pipe (G), which led the solids back to the process. The solid stream was deflected to either side, as desired, by sliding rod (I) in and out through simple bushes (J) and (K), so moving from side to side the end of flexible pipe (A), which was firmly clamped to rod (I). Stops (L), (M), (N) and (O) governed the amount of travel. The device was used for handling cold solids and the flexible pipe (A) was a piece of rubber hose. For higher temperatures, possibly a reinforced asbestos cloth would be suitable.



W. H. Newton R. S. Jones

Preventing Spillage on Material Conveyors

Originally with an extensive system of belt conveyors, it was decided to fit strips of stationary belting on each side of a particular belt, and with the lower edge of the horizontal strips in contact with the moving belt. The object was to prevent the lump material being conveyed from spilling over the edges of the moving belt. In practice, the arrangement was only partially successful for occasional lumps of the product would become trapped between the moving and stationary belts, eventually to be catapulted over the operating area. By increasing the clearance between the two belts to approximately 2 in., the ejection of the material was prevented and, despite the gap, the stationary belts are adequate for retaining the conveyor charge upon the travelling belt.



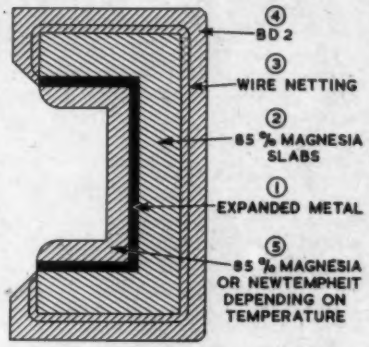
Preformed Flange Covers

THE ORTHODOX METHOD of lagging flanges is to apply the required thickness of 85% magnesia compound and enclose this in wire netting to form a keying surface for the protective outer coating of an asbestos-filled hard facing (e.g., B.D.2, manufactured by J. W. Roberts Ltd.). This applies not only to pipe flanges but also those on vessels, and it is on the latter that the greater saving can be made. When a flange has to be broken for any reason, the whole of the cost of the lagging is lost and the work has to be done over again. The improved method is to make up boxes to fit the flanges which can be removed and replaced as frequently as is necessary. The cost is then that of labourers' time only.

The method of constructing the boxes is as follows:

(1) a channel of expanded metal is formed of the required size;
(2) eighty-five per cent magnesia slabs are built up around the outside of the channel and fastened to it;
(3) the magnesia is enclosed in a wire netting which is joined up to the edges, thus containing the magnesia and also forming a keying surface for the B.D.2;
(4) the whole of the outer surface is coated with B.D.2 hard setting compound; and
(5) the inner surface is coated with 85% magnesia or other suitable lagging material depending upon the face temperature.

The sections are then placed around the flange and fastened with a signode band.



Cross-sectional diagram of preformed flange cover

A. ELLIS

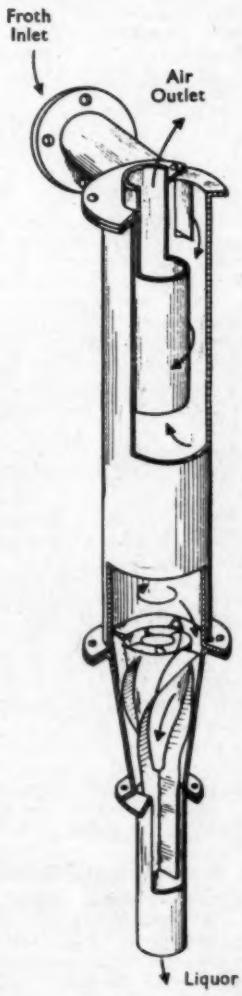
(by courtesy of the I.C.I. Wilton Services Works)

Gas Purification Plant Oxidiser and Defrother

ONE WET PROCESS for the removal of sulphuretted hydrogen from carburetted water gas relies upon the absorption of this impurity in a solution of sodium carbonate. This solution, when saturated with hydrogen sulphide, is reacted with hydrated ferric oxide in suspension to yield hydrated ferric sulphide. This latter is subsequently oxidised by means of air to give hydrated ferric oxide and to liberate sulphur. At the plant in operation at the Wales Gas Board's Cardiff plant, which has a unit employing this system of purification, the oxidation stage is carried out in a very elegant manner by means of jet pumps which use the combined ferric sulphide suspension and sodium carbonate solution as the pumping fluid. Thus air for oxidation is entrained at these pumps and intimately mixed with the suspension to be treated. Apart from extensive surface for the oxidation which this method provides, the arrangement does away with the need for a separate air compressor. The effluent from the jet pumps is fed into the oxidising vessels in which the sulphur is precipitated and the oxidised liquor, once it is free from sulphur, is fed back to the gas treatment vessels.

In similar plants where the froth produced at the oxidisers has proved difficult to remove, the method that has been used is to pass the froth into settling tanks in the hope that it will subside. This it seldom does completely, with the result that difficulties arise in the recovery of sulphur and in the re-use of the liquor.

At Cardiff, however, this problem has been surmounted in a very economical manner. The defrothers through which the discharge from the oxidising vessels is passed are cyclonic in form. The froth is broken down as soon as it is formed and the sludge is passed to storage vessels. The defrothers have no moving parts and automatically remove any formation of froth. The energy required to operate them is obtained by sealing the tops of the oxidising vessels and by applying to them an air pressure of 9-12 in. w.g.



Abstracted from a paper, "Operation of Liquid and Gastechnik Purification Plants at Cardiff", by J. Powdrill to the Inst. Gas. Engrs., May, 1959.

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

World of Chemicals

British Fertilisers

Fisons have introduced a new "40" range of compound fertilisers. The new range differs from the company's previous products in that ammonium sulphate is superseded by ammonium nitrate to provide the essential nitrogen content. The result is a more concentrated compound fertiliser which, it is claimed, will do more work weight for weight. Costs will therefore be reduced through savings in handling and application. The ammonium nitrate is being produced at Fisons' new £4.5 million factory at Stanford-le-Hope, Essex.

The compound will be introduced in two ranges: one suited for intensive production from grassland by enabling the grass to grow earlier and the other designed for soils with a high phosphate status—for potatoes, sugar beet and mangolds, as well as spring cereals and grass for silage on potash-deficient soils.

Lawes Chemical Co. has made substantial reductions in the prices of its compound fertilisers. Several of these are over £1 per ton and others approach this figure. The price reduction on Lawes Extra (10.10.18) is such that the company claims it is now the lowest priced fertiliser on the market with this analysis.

W. & H. M. Goulding Ltd., fertiliser manufacturers, have appointed Simon-Carves Ltd. as main contractors for the design and construction of the final development of their £2-million Marina Works at Cork. The contract now placed with Simon-Carves substantially exceeds £1 million. When completed in a year's time, the 18-acre Marina Works will be one of the biggest industrial undertakings in Eire and one of the most modern and economic fertiliser factories in the world.

Refineries

Preliminary site investigation work has started at the Turkish port of Mersin, and construction of a new refinery with a capacity of some 3,000,000 tons a year of crude oil is due to begin in about six months. The refinery, being built for a group of companies, includes B.P.

Now under construction at Shell Haven refinery in the Thames Estuary, at a cost of more than £2 million, is a hydrodesulphuriser for the removal of sulphur from petroleum products by the Shell "trickle-phase" technique. In this operation, gas oil to be desulphurised is contacted with hydrogen and made to trickle over a special catalyst. The hydrogen converts the sulphur compounds into hydrogen sulphide which will be processed to make some 20 tons a day of pure liquid sulphur.

The first stage in the construction of B.P.'s new Canadian refinery at Ville d'Anjou near Montreal is complete. Its main aim has been to provide tankage and loading facilities so that products can be stored and distributed to B.P.'s growing Canadian market. Stage two of the construction programme includes the erection of the processing units to deal with a crude throughput of 1,000,000 tons a year and is due for commissioning in mid-1960. Until then crude oil is being processed into B.P. products under a contract with a nearby refinery.

Canadian Chemicals

The factory value of products shipped by Canada's chemicals and allied products industries reached a new peak in 1958, rising 8% to $1,300,797,000 from the preceding year's $1,203,411,000, the Dominion Bureau of Statistics reports in an advance statement. Among the 14 individual industries comprising the chemicals and allied products group, the largest proportionate increase in factory value of shipments (19.8%) was recorded by heavy chemicals. Soaps and washing compounds was next with an increase of 11.0%, medicinal and pharmaceutical preparations 10.1%, polishes and dressings 9.3%, paints and varnishes 9.0%, adhesives 8.8%, toilet preparations 7.7%, fertilisers 7.6%, primary plastics 7.5%, compressed gases 7.4%, and miscellaneous chemicals 1.0%. Only three industries—coal tar distillation, inks and vegetable oils—showed declines in the factory value of shipments as compared with 1957. Imports by the chemicals and allied products group of industries were valued at $290,400,000 in 1958 as compared with $293,800,000 in the preceding year, and exports were valued at $197,100,000 as compared with $195,300,000.

Canada's First Thorium Plant

The increased demand for thorium, which has important applications as a heat-resisting alloy with magnesium for rocket engineering, will be met in part by Canada's first thorium plant, at Elliot Lake, Ontario, in the Blind River uranium field which is now in production. It was built in six months by Humphreys & Glasgow (Canada) Ltd. for Rio Tinto Dow Ltd., and cost in the neighbourhood of $1,000,000. Scheduled output, which is approximately 150 tons of thorium salts a year, represents a substantial proportion of the current world production. It is the first installation in the world to recover thorium from waste liquors produced in uranium milling.

American Acetylene-based Chemicals

The recently-announced plans of the Dow-Badische Chemical Co. to produce acrylic acid and methyl, ethyl, butyl and other acrylic esters at a plant under construction near Freeport, Texas, underlines the expansion of acetylene-based chemical production. Production is expected to begin in January, 1960, following completion of the plant in December, 1959. Construction has been in progress for the past eight months at a site adjacent to Dow's Texas Division. The acrylic acid will be manufactured as a 94% technical grade by a direct process developed by Badische. In addition, acrylic esters will be produced by esterification with methyl, ethyl, butyl and other alcohols.

French Butadiene

Reflecting the expanding market for synthetic rubber and wider applications of the material in the paint and varnish industry is a new French butadiene plant. This plant, which extracts butadiene from cracked gases, is to be built by Naphtachimie S.A., in which Société Francaise des Petroles BP has a substantial interest. In the first stage some 7000 metric tons a year of butadiene will be produced. Naphtachimie's plant is situated adjacent to the Lavera refinery of Société Francaise des Petroles BP, near Marseilles.

Swedish Vinamul Emulsion

The general trend towards closer co-operation between the Scandinavian countries and the U.K. outside the European Free Trade Area is strongly underlined by the association of Skanska Attikfabriken A.B. of Perstorp and Vinyl Products Ltd. of Carshalton, Surrey. One consequence of this association is that Skanska Attikfabriken have recently begun full-scale production of the Vinamul and Vinalak ranges of synthetic resin emulsions and solutions. It is hoped that this venture will satisfy the large Swedish demand for this type of product, hitherto met by imported materials.

Registration of Australian Chemists

State pharmacy boards in Australia have agreed to the extension of a reciprocal registration system for pharmacists in Australia, Britain and New Zealand. The Federal President of the Pharmaceutical Association of Australia said the extension meant that chemists would not need to pass State examinations if they had had at least 12 months' practical experience in pharmacy in any of the three countries.

Australian Plastics

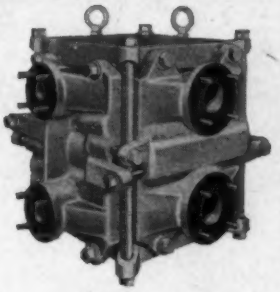
The American Goodrich Chemical Co. is to build a plastics factory in Australia at a cost of £A2 million. The company states that the factory would be built in co-operation with Australian interests. The factory will make deon polyvinyl chloride plastic materials, which are expected to save Australia about £A1 million a year in foreign exchange. Deon is a basic material for many articles, including rainwear, gramophone records, floor tiles and electrical insulation.

Multi-Million Celebration

A new multi-million dollar nylon plant at Greenwood, South Carolina, a multi-million dollar research laboratory in the Research Triangle Park of North Carolina and a new nylon development centre at Pensacola, Florida. These are developments announced by the Chemstrand Corp., chartered on May 16, 1949, as a joint venture of Monsanto Chemical Co. and American Viscose Corp., during the months in which it is celebrating its tenth anniversary.

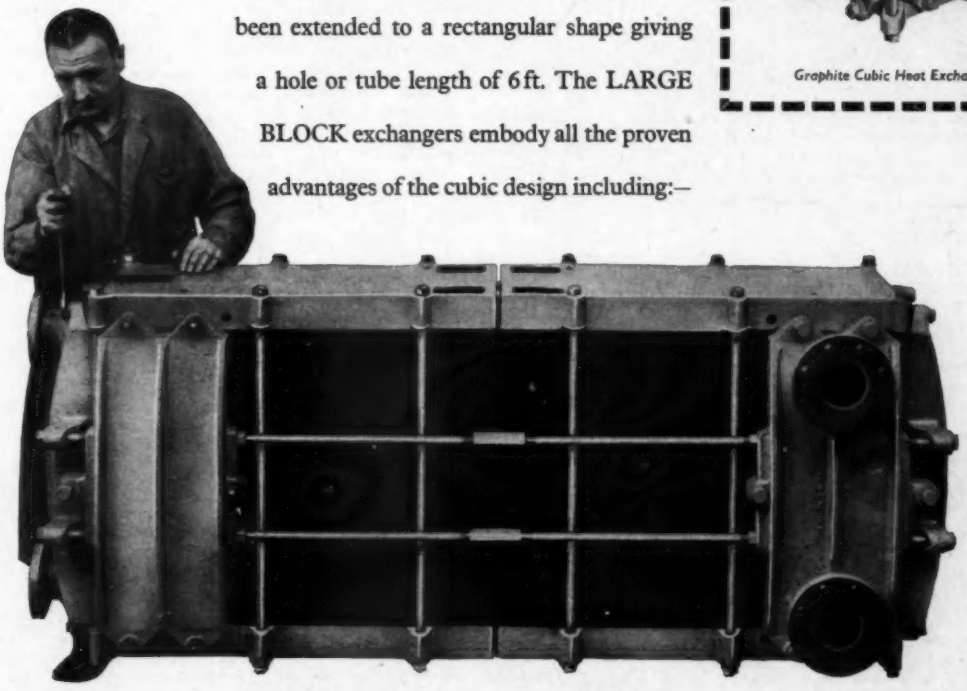
LARGE BLOCK
GRAPHITE HEAT EXCHANGERS

THREE NEW MODELS NOW AVAILABLE PROVIDE HEAT SURFACE AREAS OF 100, 150 AND 200 SQ. FT. WITH HOLE (TUBE) DIAMETERS OF $\frac{3}{4}$"



Graphite Cubic Heat Exchanger.

The design of these new models is basically that of the patented CUBIC heat exchanger except that the graphite sub-assembly has been extended to a rectangular shape giving a hole or tube length of 6 ft. The LARGE BLOCK exchangers embody all the proven advantages of the cubic design including:—



- Corrosion resistance on both sides to most acids, alkalis and solvents:
- High overall heat transfer under conditions of heating, cooling, evaporation or condensation.
- Standard equipment yet giving controlled velocities for both fluids, over a wide range of flow rates.
- Compact and robust (no floating or flexible parts).
- Good accessibility for cleaning and maintenance on both sides.

POWELL DUFFRYN
DELANIUM
CARBON & GRAPHITE
CARBON PRODUCTS LIMITED

Powell Duffryn
CARBON PRODUCTS LIMITED

SPRINGFIELD ROAD, HAYES, MIDDLESEX. PHONE: HAYES 3994

Book Reviews

Chemical Engineering Practice, Volume 5: Fluid Systems I
by H.W. Cremer and Trefor Davies
Butterworths. London, 1958, 695 pp., 95s.

VOLUME 5 of "Chemical Engineering Practice" has the title "Fluid Systems I" and, as might be expected from this title, the book contains a considerable amount of fluid mechanics. The first three sections are concerned with the transportation of liquids and gases; in particular with pumps, compressors and pipe systems. Editorially, it would have been better to have presented this together with the excellent text-book treatment of fluid mechanics which was given in Volume 4, since the latest contribution is essentially of a practical nature. It contains just about all the non-specialist engineer is likely to require to know about different types of pumps and compressors, with useful worked examples of design calculations. There is a good deal of practical information on the design, construction and operation of these machines. The section on pipe systems follows the same pattern.

The next section in Volume 5 is concerned with the design of high-pressure vessels. It is stated that, while the standard pressure vessel codes give detailed design procedures for pressures up to about 3000 psi, for the much higher pressures at which some chemical processes are carried out the engineer must base his design largely on first principles. The authors in the next 100 pages give a good discussion of these principles, and show how they can be applied.

Fluid mechanics reappears in the next chapter, under the heading "The production of vacuum". This contribution is devoted essentially to the practical side, with useful procedures for the sizing of pumps, pipes and components, with worked examples.

The second half of Volume 5 contains what might be called the Birmingham University contribution on solvent extraction and distillation. There are 330 pages of this, and the authors obviously had a difficult task in trying to make their contributions not identical with current text-books. They have succeeded remarkably well. Inevitably most of the standard text-book material is there, but there is also a great deal which is not included in text-books, and it is probably the most comprehensive presentation that has appeared in a single volume. Most of the authors are known for their original work in the subject and their contributions are very much up-to-date. The chapter headings are Liquid-liquid Equilibria, Liquid-liquid Stagewise Contact, Extraction Equipment, Vapour-liquid Equilibria, Rectification of Binary Mixtures, Multi-component Distillation, and Distillation Equipment. Remembering that the authors are university people, there is a surprising amount of practical information in these sections, particularly on the characteristics and performance of actual equipment.

When the Chemical Engineering Practice series was first proposed, there was a good deal of scepticism about the value of the work. There is no doubt that the series has proved much better than many people hoped, and Volume 5 must be particularly pleasing to the General Editor, MR. H. W. CREMER, in that the theoretical side is worthy of a university textbook while the practical side is genuinely immediately useful to a practising engineer.

Thermodynamics
by Gordon J. Van Wylen
John Wiley & Sons, London, 1959, 567 pp., 64s.

THIS is an elementary text-book of thermodynamics written for undergraduate students of mechanical engineering in American universities. The book starts by describing typical pieces of engineering equipment whose design depends on an appreciation of the thermodynamic laws and by defining quantities such as pressure, temperature and force. The equations of state and phase relationships of pure substances are then briefly outlined and then the first and second laws of thermodynamics described. These laws are then applied to the behaviour of ideal gases and the efficiency of heat engines. The thermodynamics of flow through nozzles and across turbine blades is then treated, followed by the use of thermodynamic charts and tables. Finally, chemical equilibrium calculations are applied to problems in combustion. The book ends with a selection of thermodynamic data for gases and the answers to problems given liberally throughout the text. The whole is lucidly expressed and brought up to date by examples taken from gas turbine and rocket technology. The outstanding impression which the book makes is the degree to which mechanical engineering thermodynamics and chemical engineering thermodynamics have at last begun to move towards each other in the ways in which they are taught. From this point of view of providing common ground and language, the present volume should fulfil a need which has been present for a long time.

P. H. CALDERBANK

Research for Industry, 1958
H.M.S.O., 1959, 7s. 6d.

THIS IS ONLY the second year of separate publication for the report of the work of industrial research associations which was formerly incorporated in the D.S.I.R. Annual Report. It contains the Industrial Grants Committee's statement of policy, a review of achievements, two special articles on research topics and a complete list of the R.A.s, describing the scope of each. The policy statement includes these observations. "We are firmly of the view that co-operative research brings important specific benefits to industry. It economises on money and scientific manpower. It offers a scientific service to firms that cannot afford research departments of their own. It helps to guide industry towards an appreciation of the value of research in general.... Finally, it builds a store of knowledge on which the nation, through government departments, can draw."

Molecular Science and Molecular Engineering, 1959
Edited by A. R. von Hippel
The Technology Press of M.I.T. and John Wiley & Sons Inc., New York. Chapman & Hall, London, 1959, 446 pp., 148s.

THIS co-operative volume is the third of a series devoted to modern materials research. The appeal is primarily to physical scientists and engineers, and the intention is to relate atomic and molecular phenomena to macroscopic behaviour having a practical interest. It is the philosophy behind this approach that eventually molecular engineering will be possible, and to some extent is already so, so that from the behaviour and properties of molecules, atoms and ions, the behaviour and properties of assemblies of these, in the form of macroscopic materials of engineering value, may be predicted and novel devices imagined. The extent to which this can now be done varies considerably from one field to another.

The topics which have received attention in this volume include macroscopic laws and their molecular interpretations; formation and structure of atoms and molecules; conduction in gases; thunderstorms; microwave breakdown; gas discharges; explosions; gases, liquids and solids; chemical crystallography; reaction mechanisms in liquid systems; polymer synthesis and stereospecific polymers; crystal growth and perfection; irradiation of materials; plasticity in crystals; ferroelectrics, antiferroelectrics, and ferromagnetics; ferromagnetic and piezo- and ferro-electric devices; masers and film memories; charge carriers in liquids and solids; polyelectrolytes and ion-exchange resins; rectifiers and transistors. Throughout this varied range of topics the theme of the molecular, ionic and atomic basis of behaviour is on the whole adequately sustained. It is not possible for a single reviewer to speak authoritatively about all the subjects discussed. It is also possible to be critical concerning a work in which no attempt is made to confine the material presented to one or other of the orthodox divisions of science and technology, but which instead ranges freely among selected chemical, physical and engineering topics.

This attitude, however, is not justifiable in the opinion of the reviewer. The formal divisions of science are wholly artificial, and it is refreshing to see them deliberately disregarded. Indeed, the aims of this book could not be realised through, for example, a purely chemical or a purely physical perspective. It is a considerable stimulus for specialists in one or other science to read authoritative surveys in different sciences which have been correlated by emphasising throughout the underlying electrical, atomic and molecular behaviour of matter. This book should

CHAPMAN & HALL

★ *New British & American Books* ★

The Design and Construction of HIGH PRESSURE CHEMICAL PLANT

by

HAROLD TONGUE
M.I.Mech.E., A.M.I.Chem.E.

SECOND EDITION—REVISED

264 pages *Illustrated* *84s. net*

Sir John Cockcroft says in his Foreword: "The time is opportune for a new edition of Mr Tongue's book, for much development has occurred since its first edition in 1934, not only in the greatly increased use of high pressure in the chemical industry, but also in the applications of high pressure technology in the design of reactors and auxiliary equipment for nuclear power plants, some of which are really chemical engineering projects."

★

A new Russian Translation published in association with CONSULTANTS BUREAU, INC.

CORROSION OF CHEMICAL APPARATUS

by

G. L. SHVARTZ & M. M. KRISTAL

254 pages *Illustrated* *60s. net*

Containing information hitherto unavailable in one volume in English, this monograph is a result of the investigations carried out by the authors at the Scientific Research Institute of Chemical Machines and the Moscow Institute of Chemical Machines. They present valuable data concerning the theory of intercrystalline and stress corrosion, and then discuss in detail the causes and character of corrosion cracking of carbon steels, alloyed steels, and non-ferrous metals.

★

From John Wiley & Sons, Inc.

ORGANIC SEQUESTERING AGENTS

A Discussion of the Clinical Behaviour and Applications of Metal Chelate Compounds in Aqueous Systems

by

S. CHABEREK & A. E. MARTELL

631 pages *Illustrated* *200s. net*

This book stresses two important areas of co-ordination compounds that have not been adequately treated in previous works. It offers a clear and up-to-date discussion of the principles governing the interaction of metal ions with aqueous complexing and chelating agents. It also provides a comprehensive summary of the many applications of chelating agents and metal chelates.

37 ESSEX STREET, LONDON, W.C.2

RG

TUBE CUTTING AND SCREWING MACHINES

available as portable or bench models with petrol, electric, compressed air or dual drive for producing all types of screw threads from ⅛" to 4" diameter.

"R. G." machines may be hired.

For further details write for leaflet No. N. G. 56

SOME USERS OF THE "RG" MACHINES.

AIR PUMPS LTD., London, S.W.20.
H. P. BULMER & CO. LTD. Hereford.
HEAD WRIGHTSON LTD. Thornaby-on-Tees.
DORMAN, LONG & CO. LTD., Middlesbrough.
G. H. HADEN & SONS LTD., Birmingham.
YOUNG, AUSTEN & YOUNG LTD., Manchester.
THE KUWAIT OIL CO. LTD., London, W.1.
MATTHEW HALL & CO. LTD., London, N.W.1.
NORTH EASTERN GAS BOARD Liverpool, 1.
STEWARTS & LLOYDS LTD., Halesowen, Nr. Birmingham.
THE TATA IRON & STEEL WORKS, Calcutta, India.
CITY OF SHEFFIELD EDUCATION COMMITTEE, Sheffield, 1.
COLVILLES LTD., Glasgow, C.2.
BRITISH CELANESE LTD., Derby.
J. LYONS & CO. LTD., London, W.14.
SOUTH EASTERN GAS BOARD, London, S.E.26.
ROLLS-ROYCE LTD. Derby.

The "Barson" Metal Cutting Circular Sawing Machine.

"Bewege" Patent Precision Hand Lever Shears.

"CXE" Tube Bender

For further particulars please apply to:

J. C. NEVILLE LIMITED

34 PRIESTS BRIDGE, LONDON, S.W.14, ENGLAND

Telephone: PROspect 8796 E.1.

Book Reviews (continued)

therefore have an appeal to a wide scientific public. The format and printing are very good, and the figures, tables and illustrated diagrams are particularly praiseworthy.

R. M. BARRER

Elasticity and Plasticity
by J. Goodier and P. Hodge
Chapman & Hall Ltd. (John Wiley Inc.)
London, 1959, 152 pp., 50s.

THIS book is Volume 1 of the Wiley series "Surveys in Applied Mathematics". It is in two parts, the portion on the "Mathematical Theory of Elasticity" being written by PROFESSOR GOODIER and that on the "Mathematical Theory of Plasticity" by PROFESSOR HODGE.

The first section contains 44 pages, and deals with such problems as Plane Stress and Plane Strain in an Isotropic Medium, Approximate Conformal Mapping, Reinforcement of Holes, Anisotropic Elasticity, Thermal Stress, and Wave Propagation. A large amount of information is packed into this short section, the mathematics is concise, and little attempt is made to deal with fundamentals. The declared object of the section, in fact, is to review significant recent developments in the mathematical theories, with emphasis on foreign papers, and in particular on Russian work. The author has succeeded in presenting a very comprehensive review, and refers to about 150 papers. Of particular interest is the description of the method of conformal mapping due to KIKUKAWA, which enables useful shapes which occur in practice to be mapped, and partially removes the limitation of the conformal method to mathematically simple but improbable contours.

The second section of the book covers some 100 pages, and the author has been able to go into more detail than was done in the first section, since less work has been published in the field of plasticity than in that of elasticity. The first four chapters deal with fundamental concepts, such as the theory of perfect plastic solids, strain hardening, piecewise linear plasticity and the application of minimum principles to the theory of plasticity. Chapter 5 deals with the bending of a circular plate and chapter 6 with other problems. The last chapter is a survey of Russian work in the field. Finally there is an excellent bibliography containing over 170 references, followed by a bibliography of Russian contributions containing reference to about 170 Russian papers and books. As in the first section, the emphasis here is on the mathematics, but PROFESSOR HODGE has been able to include more basic theory, and so less demands are made upon the experience of the reader in this field.

Both sections of this book can be highly recommended as long as it is realised that the book is not meant to be a text-book of elasticity and plasticity. The reader is expected to have considerable background knowledge of the mathematical theories, and the standard required is high. It must be realised that the book is intended as a survey of recent work, and, viewed within this limitation, it should prove extremely useful to those already interested in the mathematical theories of elasticity and plasticity, particularly in that it brings to their notice work which might otherwise be ignored because of language difficulties.

N. H. LANGTON

Chemiewirtschaft in Zahlen
3rd Edition. Econ-Verlag, Dusseldorf, 1958.

THE MAIN FIELD covered by this compendious pocket booklet is naturally the production of the German industry. Figures are given in considerable detail —production, export, import, consumption of coal, oil, gas, electricity, often divided into sections of the industries and integrated for both chemical and other major industries. Great care has been taken to make figures truly comparable, and useful comparisons may be made between chemical and other industries and between countries. The foreword discusses the limitations of the effort as a whole due to the complicated economic structure of the chemical industry and the risk of double-counting; there are then separate notes commenting on each table. Half of the booklet is devoted to other countries and the scrupulous care of the compilers is well exemplified by their giving figures based on both German definitions of the limits of the chemical industries and on those of the countries concerned. The one addition that might have been made to this valuable booklet is a set of graphs.

I.B.

Index of Chemistry Films—A comprehensive list of films and filmstrips on chemistry and related topics.

Published by The Royal Institute of Chemistry, London, 1959, 5s.

THE Royal Institute of Chemistry has made an important contribution to visual aid information in this Index, which provides details of more than 800 films and 200 filmstrips on chemistry and related subjects. The Index has been "designed to cover the requirements of schools, technical colleges, universities and training departments of industrial firms, and it includes films and filmstrips of many types, from those of an elementary nature up to research films. The selection of such a publication." continues the foreword. "has presented great problems for the fields of interest of chemists are wide and in places, hard to delineate precisely. The attempt to cover all likely requirements has resulted in the inclusion of some topics on which only background films are at present available. There is an evident shortage of educational films and filmstrips in certain branches of chemistry, and a study of the Index will show where and how great this shortage is."

A subject index is supplemented by a list of the films and filmstrips by titles, and with the addresses of distributors. The Index does not, however, refer readers to other sources of information. This is a pity, because although this is by far the most comprehensive list of films on chemistry it limits itself to a brief description of each film, with only an occasional reference to audience suitability. A notable omission is that of dates of production, which means that not only can the reader not distinguish, in most cases, between an old and a recent production (an important point when techniques change or when a film may date because of its setting or the context in which it was made—wartime films, for example, usually make pretty heavy weather when screened today), but is also unable to tell easily whether he has traced a film of great historical or technical interest or is likely to be able to obtain the very latest production in a particular field.

In view of this, it would have been helpful to refer readers to other sources. The Scientific Film Association, for example, published in the June, 1956, issue of "Scientific Film Review" details of over 200 chemistry films. Some of these are reviewed in detail, most of them dated. Subsequently issues of the journal have reviewed in detail other chemistry films.

A.M.H.

Plumbing, Materials and Techniques
by Sydney Webster
Batsford, London, 1959, 218 pp., 30s.

THIS book will be invaluable for the maintenance gang handyman of a small works who may have to tackle a variety of plumbing jobs which do not warrant the advice of an expert. It will also be of value to the men (and staff) of a large works who specialise in this type of work as a book of reference. There is an engineering air about this book—its format is logical and deals first with materials of construction, this is followed by methods of fabrication and finally with the applications of the techniques described. It may also have a greater value than its authors intended. For instance, with the information given in the chapter on "Lead and Lead Alloys", the repair of lead-lined chemical plant may be undertaken. Similarly, in other chapters, they give a great deal of practical guidance on works services for instruments, air, steam, etc. Perhaps the book attemps to give a little too much information within its covers and the diagrams tend to be cramped, a shortcoming which detracts from their clarity, with the result that often the excellent details cannot be fully appreciated. A cross-reference in the chapter on Aluminium (section 14, Aluminium Rainwater Goods) should be made to corrosion caused by "Contact with other material"—given on p. 81. No mention is made of the large water supply tanks now placed on top of the tall blocks of modern offices and flats, nor of the pumps necessary to get the water to them. The only pumps described are hot water circulators. These are, however, but minor criticisms of an otherwise useful book.

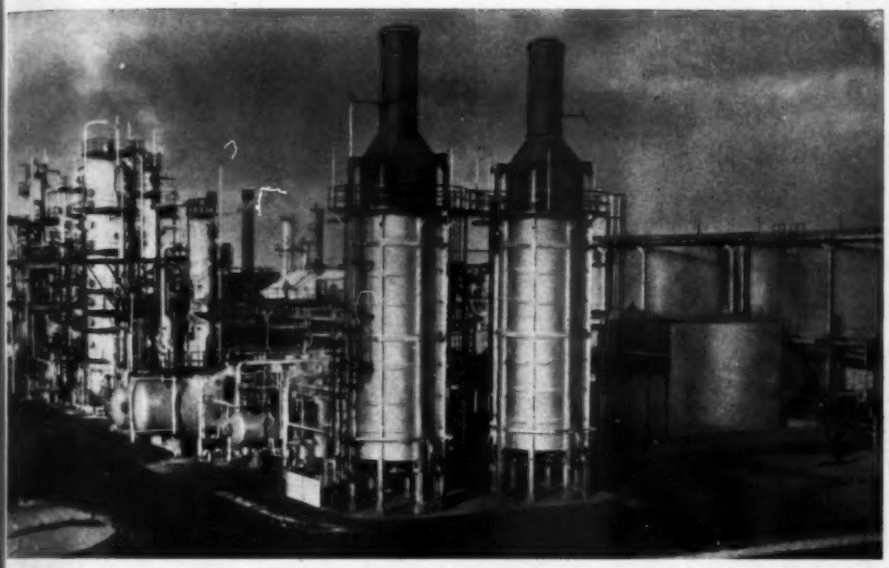
J.A.W.

NEWTON CHAMBERS

BCE 5880 for further information

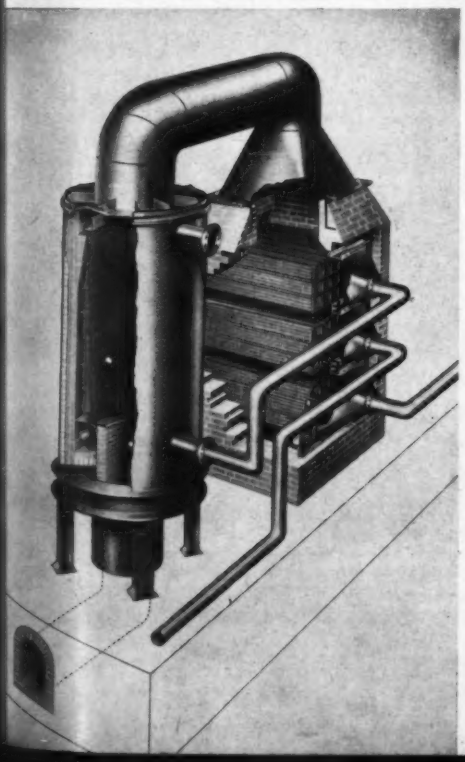
ENGINEERS OF PROGRESS

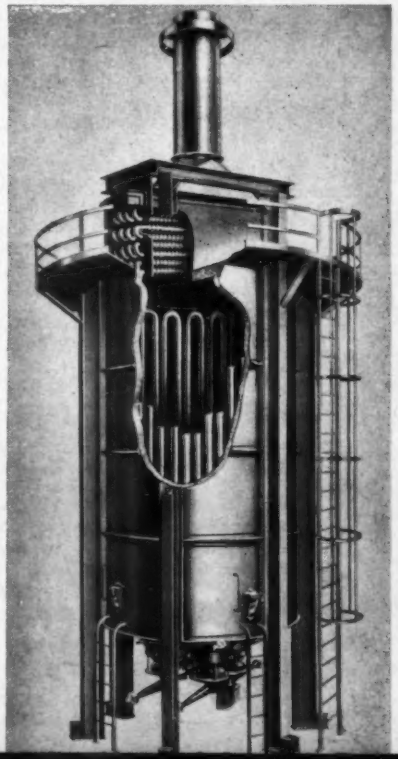
Important New developments in Heat Exchange Equipment



BELOW *Combined INKA Radiation and Newton Needle Convection Type Recuperator Installation.*

ABOVE AND BELOW RIGHT *The well-known Struthers Wells equipment for industrial heating at elevated temperatures is offered direct to British industry.*





NEWTON CHAMBERS are better equipped than ever before to offer a comprehensive service covering Heat Exchange equipment. Extensions to the constructional shops at Thorncliffe now permit the handling of larger fabrications more efficiently. Facilities include welding to Class 1 standards, stress relieving and x-ray examination.

In the highly specialised field of Heat Exchange Newton Chambers offer the experience of years of specialised design, fabrication and manufacture. Recent developments include the completion of important agreements with American and continental organisations to manufacture Struthers Wells Industrial Heating equipment, the INKA Preheater for preheating air, steam and combustible gases up to 875°C, and other Heat Exchangers.

Newton Chambers are pleased to advise on all Heat Exchange problems and to quote for the most suitable installations.

Newton Chambers

ENGINEERING DIVISION

NEWTON CHAMBERS AND COMPANY LTD
THORNCLIFFE · SHEFFIELD

20167

PLANT EQUIPMENT NEWS

Solenoid Semi-balanced Valves

Jones Tate solenoid-operated semi-balanced valves, Series 319, is a range of heavy-duty solenoid-operated globe pattern valves of the semi-balanced type designed for the control of fluids, including gases in industrial processes. The standard range of valves is made in sizes ½-4 in bore, suitable for pressures ranging from vacuum to 200 psig. Special valves are also available for operation at higher working pressures up to 2000 psi or at elevated temperatures. All valves can be fitted with supplementary manual-operation means and interlock switches. **Jones, Tate & Co. Ltd., Victory Works, East Parade, Bradford, 1.**

BCE 5991 for further information

Triple Roller Mill

Cox's Machinery recently marketed a new triple roller mill for use in the preparation of paint, printers' ink, fine powders, etc. For special purposes the mill can be specially adapted, the gear ratios, cambers and overall speeds of the rollers being altered to suit the particular job. The roll dimensions are 15¼ in. by 37½ in. and the machine is driven by a 40/50-hp motor. The motor drive is enclosed under the machine and the mill is controlled hydraulically with handily placed knobs. **Cox's Machinery Ltd., 25 St. Thomas Street, Bristol, 1.**

BCE 5992 for further information

Vacuum Pumping

The increased use of gases such as oxygen, nitrogen, argon and methane in liquid form has led to many problems with regard to storage. One accepted method for storing and transporting liquid gases is to use double-walled vessels with a powder-filled interspace which is pumped to a relatively high degree of vacuum. In conjunction with their own design engineers, Edwards High Vacuum recently produced for the Billingham Division of Imperial Chemical Industries Ltd. a series of special mobile pumping units for vacuum insulation of liquid argon containers. The illustration shows one of these pumping outfits evacuating the interspace of a large liquid argon vessel at Billingham. This pumping system was designed specially for I.C.I., but Edwards state that larger or smaller units can be built to suit other applications in this field. **Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.**

BCE 5993 for further information

Fluorosint

A material known as Fluorosint and said to be an entirely new fluorocarbon T.F.E. base resin, comprising P.T.F.E. and other specially developed constituents designed to improve the mechanical and thermal properties of P.T.F.E. without materially affecting its unique electrical and chemical characteristics, has been announced by Polypenco. The properties are briefly summarised as follows: coefficient of thermal expansion is approximately one-sixth that of P.T.F.E. and is similar to aluminium, copper and a number of other metals, thus solving problems of fits and clearances of parts on thermal cycling, when used in association with such metals; dimensional tolerances of parts in Fluorosint can be held to limits that are one-third to one-sixth those attainable with P.T.F.E. Fluorosint parts are notably free of stresses and do not distort on thermal shock or temperature cycling; deformation under load is considerably less than with P.T.F.E., especially at elevated temperatures. Hardness is increased and creep or cold flow greatly reduced; bearing and wear characteristics show a marked improvement over P.T.F.E. Bearings can operate at much higher loads and speeds; the electrical properties are closely comparable to P.T.F.E. over the entire frequency range. Chemical properties are virtually identical. The new material is similar to P.T.F.E. in that it is resistant to almost all chemicals. Its chemical resistance combined with its outstanding mechanical properties permits it to be used for bearings and bushings operating in corrosive conditions or under water, as well as for gaskets, packings, washers, valve seats and similar parts. It is available in the form of rod and tubular bars for fabrication into component parts or, alternatively, parts can be moulded by the company to customers' requirements. **Polypenco Ltd., 68-70 Tewin Road, Welwyn Garden City, Herts.**

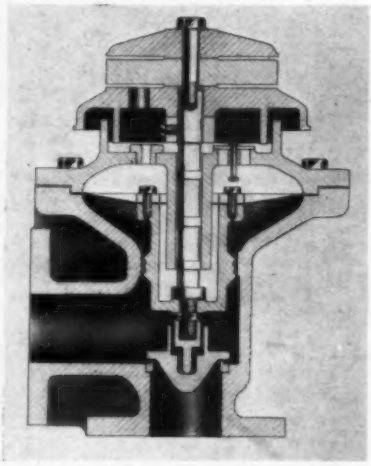
BCE 5994 for further information

Automatic Conductivity Measurement

A new range of Philips automatic conductivity measurement equipment permitting continuous measuring, recording and control of the strengths of process solutions is now being distributed in the U.K. The equipment is made in Holland. Two methods are available: one is available with automatic temperature compensation, the other involves the use of a reference cell immersed in the liquid being examined, in which case no temperature compensation is required. With single channel recorders, the strength of the process liquid may be continuously controlled, in addition to being measured and recorded. Where measurement and recording only are required, multi-channel recorders monitoring up to six different points may be used. **Research & Control Instruments Ltd., 207 King's Cross Road, London, W.C.1.**

BCE 5995 for further information

Pressure Relief Valve



A dead-weight pressure relief valve recently announced has been principally designed for use under corrosive conditions on atmospheric and vacuum stills of all sizes and also chemical process vessels in the low-pressure range up to 15 psi. It incorporates a diaphragm in P.T.F.E. or standard jointing material to retain an oil seal around the vertical spindle bearing; this is designed to prevent corrosive vapours attacking the bearing. In works tests, the valve has been operated through many hundreds of cycles and has been found to be completely pressure- and vacuum-tight on completion of the tests. The standard model is supplied with a cast-iron body, with a variety of materials for the renewable seat and valve. Valves with bodies made in other materials can be supplied. **Robert Harlow & Son Ltd., Heaton Norris Brass Works, Stockport, Cheshire.**

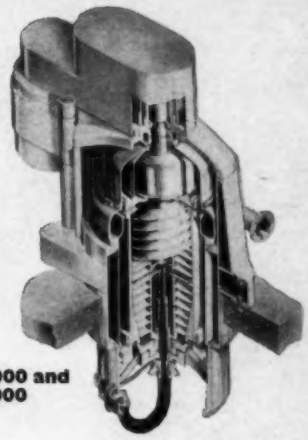
BCE 5996 for further information

Elevator for Bulk Materials

Using the screw conveyor principle, a precision-built elevator has been developed for handling bulk materials. From the base of a feed hopper two opposed horizontal spirals lead the material into a slightly inclined elevating spiral which, in turn, propels it up to a height of 5 ft 6 in. This height can be

The world's biggest range of centrifuges includes all these

New Sharples Super-D-Canters



P.4000 and P.7000

The Sharples range of continuous centrifuges not only includes machines of every type but a full range of models of each type.

Take for instance the Super-D-Canter type scroll discharge centrifuge which is widely used for centrifugal filtration of crystalline and amorphous solids from slurries. There are no less than 8 basic models.

P.400 Laboratory Scale Super-D-Canter—4″ diameter conical bowl; maximum centrifugal force 2,100 x G.

P.600 A new Pilot Plant Scale Super-D-Canter—6″ diameter cylindrical/conical bowl; maximum centrifugal force 3,150 x G.

P.1000 Full Scale Super-D-Canter—14″ diameter conical bowl; maximum centrifugal force 2,100 x G; especially suitable for handling crystalline materials where good washing is required.

P.2000 Full Scale Super-D-Canter—14″ diameter cylindrical bowl; maximum centrifugal force 2,100 x G.

P.2000-HS High Clarifying Capacity Super-D-Canter; 14″ cylindrical/conical bowl; maximum centrifugal force 3,200 x G; especially suitable for handling fine solids.

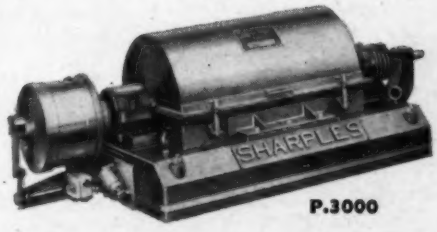
P.3000 A new high liquid throughput Super-D-Canter; cylindrical/conical bowl; maximum centrifugal force 3,200 x G; especially suitable where high throughput of slurries at relatively low solids content have to be handled.

P.4000 A new vertical type Super-D-Canter; cylindrical/conical bowl; maximum centrifugal force 3,200 x G; especially suitable for pressurised operation up to 150 p.s.i.g. at high liquid throughputs.

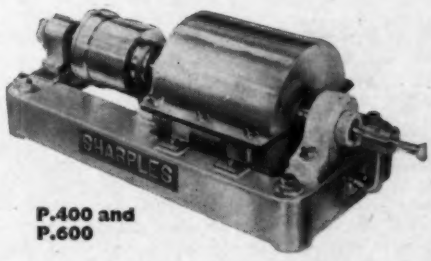
P.7000 Another new vertical Super-D-Canter suitable for very large solids throughput; maximum centrifugal force 1,700 x G; available for pressurised operation up to 150 p.s.i.g.

P.2000 and P.2000-HS

P.1000



P.3000



P.400 and P.600

For each of these models there are detailed specifications for condition of operation such as for vacuum or pressure, for low temperature, for special rinse requirements, for construction in various materials, etc.

Send for Bulletin No. 1258BM—Sharples Complete Line of Centrifuges.

SHARPLES

SHARPLES CENTRIFUGES LTD., TOWER WORKS, DOMAN ROAD, CAMBERLEY, SURREY. *Telephone: Camberley* 2601

PLANT EQUIPMENT NEWS

increased up to 11 ft by means of an extension piece which can be assembled or dismantled in less than five minutes. The unit is powered by a small electric motor through an infinitely-variable torque converter, by means of which the operator can regulate the output speed with accuracy. When fitted with a 1½-hp motor the range is from 3 to 12 tons per hour and with a ¾-hp motor a range of ½ to 3 tons is obtained. With a capacity of 4½ cu. ft, the feed hopper takes slightly more than the contents of an average sack and its feeding height above ground level is only 18 in. The machine is quiet in operation and raises no dust. The horizontal spirals run at a fairly low speed and assure effective scavenging of the hopper with no possibility of cavitation. This machine can also be used for mixing two different materials while they are being elevated, by partitioning the hopper into two compartments. Proportion is controlled by varying the pitch of the screws of the spiral feeds. The unit is mounted on trolley wheels. **Russell Constructions Ltd., Adam Street, London, W.C.2.**

BCE 5997 for further information

High-temperature Electrical Insulation

Fluoride coatings on copper, aluminium and other metal wires are reported by Bell Telephone Laboratories to provide exceptionally high insulation at high temperatures, while retaining flexibility and freedom from porosity. The insulating coatings are formed directly on freshly cleaned copper or aluminium by exposing them to carriers such as hydrogen fluoride or elemental fluorine at temperatures from 300°C to 600°C. These films remain adherent when bent repeatedly at angles of 90 degrees. Electrical insulation values are very high for both copper and aluminium films, being about 10^{10} and 10^{11} ohms at room temperature for films of some 1 to 2 microns thick, between probe electrodes ¼ in. in diameter. The films retain their excellent insulating properties at high temperatures. For example, aluminium fluoride films exhibit resistances of about 7×10^5 ohms at temperatures as high as 500°C. **Bell Telephone Laboratories, 463 West Street, New York, 14, U.S.A.**

BCE 5998 for further information

Cold Box

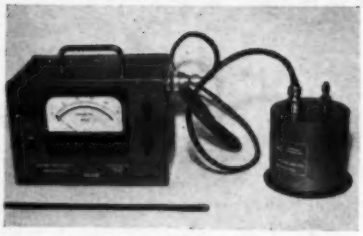
The Philips cold box installation is believed to be the first of its kind in the world with a net content of about 400 l. for temperatures down to −160°C. Refrigerating capacity at −100°C is 4400 Btu/hr and 2560 Btu/hr at −160°C. The cold box can be cooled at any preset temperature by the circulation of cold gaseous air. Liquid air—of particular importance for the transport of products in Dewar flasks, etc.—can also be produced, as can liquid air when cooling of the box is not required. Among the applications for which the installation is suitable: are preservation of biological materials such as bone, tissue, skin,

etc.; preservation of chemicals and materials during transport and/or storage; low-temperature treatment of metals; shrink fitting; prevention of ageing of aluminium and magnesium alloys; chilling of stainless steel; environmental testing of electrical components; and low-temperature chemistry. **Research & Control Instruments Ltd., 207 King's Cross Road, London, W.C.1.**

BCE 5999 for further information

Remote-reading Pressure Gauge

In a recently announced remote-reading differential pressure gauge, the transmitting unit embodies a chamber containing the capsule element assembly. A transducer slug inside a brass or stainless-steel tube is inserted inside a differential transformer. The differential transformer is electrically connected by means of a five-core cable to the indicating instrument remotely positioned. The latter comprises an open scale microammeter, calibrated to suit the range of differential pressures required. Ranges are from 0-9 in. w.g. for use with



recorder only, 10 in. w.g. and above for use with recorder or indicator/power pack. Accuracy is ±2%. Static pressure is normally up to 400 psi, but the instrument may be designed to operate up to 2500 psi on special request. The transmitter may be used in temperatures between −20°C and +70°C and the sensing membrane may be supplied to withstand temperatures of 350°C. **Appleby & Ireland Ltd., Basingstoke, Hampshire.**

BCE 6000 for further information

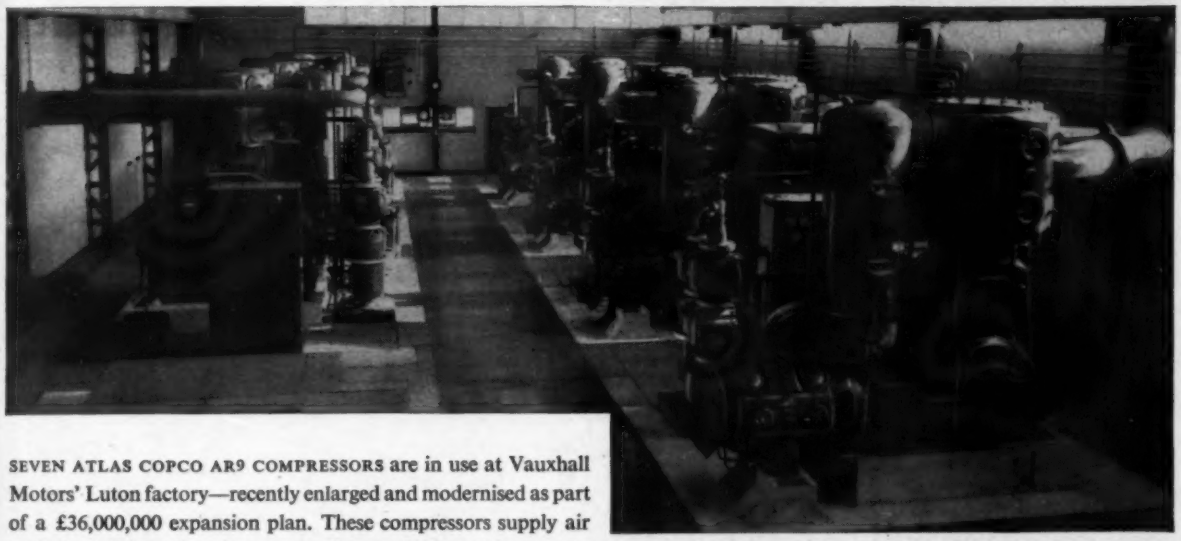
Vertical Multi-pass Boiler

A new range of vertical, multi-pass, oil-fired boilers, covering steam outputs initially from 1750 to 8300 lb./hr from and at 212°F., ranging from 4 ft 9 in. to 8 ft 6 in. diam., 11 ft 3 in., to 18 ft high with water capacities from 35 to 165 cwt. has been introduced by Cochrane & Co., Annan, Ltd., of Dumfriesshire. Known as the Series II, the new boiler embodies improved heat-transfer surfaces which enable a full load efficiency of over 80% on the gross calorific value of the fuel to be guaranteed under practical operating conditions. In the Series II a greater heat transfer than hitherto obtained is achieved by dividing the smoke-tube bank into three passes of small-diameter tubes giving a long gas travel at high velocity. The new tube arrangement also increases the surface area and, to increase the radiation transfer, the furnace has been enlarged. The boiler which is fitted with a specially-tuned pressurised jet burner by the Brockhouse Heater Co. Ltd., is such that it can be readily converted to coal-firing, a feature claimed to be by no means common with a number of types of boilers now available. This can be accomplished by removing the division plates between the passes, thus converting the boiler to single-pass operation when, if need be, it can work under natural draught.

Although the oil-fired boilers require no stack in order to achieve good combustion, Cochranes say that in practice it is as well to choose a stack of sufficient height to give adequate dispersion of the products of combustion. The stacks provided are insulated to ensure that the effects of any acid condensation are minimised. Cochranes state that the Series II is equally efficient as the horizontal boiler, with the additional advantages of saving floor space and economy of cost. As an example, they say that the floor space required for their new boiler is about half that needed for a horizontal boiler of the same output. Furthermore.

BCE 5882 for further information

Compressed Air at work in Vauxhall's Luton extension



SEVEN ATLAS COPCO AR9 COMPRESSORS are in use at Vauxhall Motors' Luton factory—recently enlarged and modernised as part of a £36,000,000 expansion plan. These compressors supply air to the body fabrication shops, press shops and other departments, providing power for clutch movements; resetting presses; mechanical handling; loading; welding; and mixing and spraying paint. In addition air is supplied for a number of pneumatic tools such as wrenches, grinders, drills and hoists.

ECONOMIC INSTALLATION

The AR9 compressors were installed at a cost below that estimated for other compressors of the same capacity. The reason being that the AR9 occupies 25% less floor space than is normally required —with consequent economies in compressor house costs.

HIGH OUTPUT

The Atlas Copco AR9 combines thorough reliability of performance with unusually high output per horsepower consumed. The installation at Vauxhall's has a total output of 22,540 c.f.m.

A COMPLETE RANGE OF COMPRESSED AIR EQUIPMENT

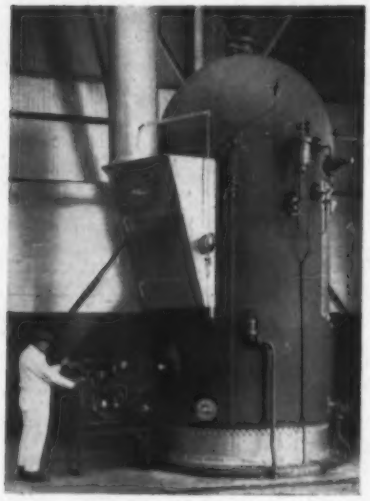
Atlas Copco manufactures portable and stationary compressors, rock-drilling equipment, loaders, pneumatic tools and paint-spraying equipment. Sold and serviced by companies or agents in ninety countries throughout the world.

Atlas Copco PUTS COMPRESSED AIR TO WORK FOR THE WORLD

Contact your local company or agent or write to Atlas Copco AB, Stockholm 1, Sweden or Atlas Copco (Great Britain) Limited, Maylands Avenue, Hemel Hempstead, Herts.

C.18

PLANT EQUIPMENT NEWS



they state that the boiler requires little additional ceiling height over its horizontal equivalent. It is the intention of the company to extend the range of evaporation for their boilers in due course and they are also actively considering the use of an all-welded boiler which should reduce the price considerably. **Cochrane & Co., Annan, Ltd., Dumfriesshire, Scotland.**

BCE 6001 for further information

Rotary Electric Vibrators

To promote the flow of solids in feeders conveyors, screens, hoppers and similar plant, Sinex Engineering have introduced a new design of rotary electric vibrator. It is manufactured in four sizes, SVA, SVB, SVC and SVD and is reported to be dust-proof, simple to install and to eliminate the need for constant maintenance usually associated with this type of equipment. It can be provided with automatic timers for intermittent operation and can also be fitted with flameproof connections. The four sizes provide centrifugal forces of 300, 500, 1960 and 7600 lb. respectively, when running at the standard synchronous speed of 3000 r.p.m. Vibrators running at 1500 r.p.m. (for handling or compacting certain difficult materials) or providing larger centrifugal effects can be built to special order. Special windings other than the standard 440 V, 3-phase, can also be provided. **Sinex Engineering Co. Ltd., North Feltham Trading Estate, Feltham, Middlesex.**

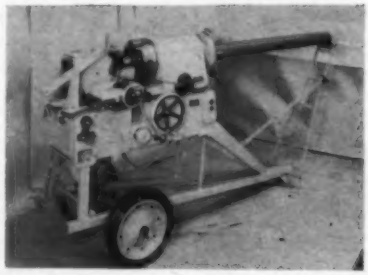
BCE 6002 for further information

Pressure-packed Solid Lubricant

Molybdenum disulphide lubricant is now being offered in a pressure pack. This pressurised 12-oz. container with internal agitator yields a non-corrosive, non-toxic, non-inflammable spray and quickly forms hard, tenacious, dry lubricating film. It is a convenient method of creating a solid MoS_2 lubricant film. The film has an operating range from −200°F (−128°C) to +750°F (+400°C), and it is therefore suitable for anti-friction bearings and gears operating at elevated temperatures. **K. S. Paul (Molybdenum Disulphide) Ltd., Great Western Trading Estate, Park Royal Road, London, N.W.10.**

BCE 6003 for further information

Automatic Tube Screwing Machine



J. C. Neville have been appointed world agents for the recently introduced R.G.-Auto entirely-automatic tube cutting and screwing machine. Operating on established R.G. principles, the machine will cut, bevel and thread tube in the diameter range ¼-4 in. at the touch of a switch. It will cut parallel or taper threads to all British and foreign standards. Specimen times achieved are: 1 in., 20 sec.; 2 in., 40 sec.; 4 in., 2 min. No resetting of the tubing is required when changing from cutting to threading, or vice versa, and only minor adjustments are necessary when changing from one thread to another. **J. C. Neville Ltd., 34 Priest's Bridge Road, London, S.W.14.**

BCE 6004 for further information

Boiler Feed Test Kit

The need of intensive testing in the boiler water field has encouraged Wilkinson & Simpson Ltd. to undertake a great deal of work on a simple form of testing based on tablets (devised by Dr. A. T. Palin). The result is that they have achieved a method which will enable the boilerman to conduct these tests and evaluate them. The tablets are not intended to displace the need for chemical control where a chemist is employed, but should prove of immense value in helping engineers to control the feed system. The tablets cover the following tests: Residual chlorine (DPD and orthotolidine methods), *p*H (from chlorine interference), Alkalinity M, Alkalinity P, Alkalinity P ($BaCl_2$), EDTA methods for total hardness, calcium hardness and sulphates, chlorides. Residual chlorine and *p*H tablets are used with Lovibond comparators and Nesslerisers. In other tests the results are obtained quite simply by counting the number of tablets required to give a distinct colour change to the sample. A unique feature of the system is that, besides eliminating chemical apparatus, glassware and standard solutions, all reagents for a given test are combined in a single self-disintegrating tablet, thus enabling the operator to perform routine control tests using no more than a bottle for the water sample and a bottle of the appropriate tablets. **Wilkinson & Simpson Ltd., Low Friar Street, Newcastle upon Tyne, 1.**

BCE 6005 for further information

Acid-Resisting Cements

The entire range of acid-resisting cements announced by Prodorite Ltd. last summer is now available. Their formulation avoids the inclusion of halogen compounds so that they can be used for installing brick linings into stainless-steel and lead-lined vessels without detriment to the material with which it is in contact. At the same time, the new formulation has permitted greater compressive strength, lower porosity (inherent in all silicate cements) and a greatly improved adhesion to ceramicware even after immersion in acids.

The new Asplit synthetic resin cements grades "CN" and "O" give the widest known chemical resistance, combined with excellent strength and adhesion, etc. The "CN" grade is an expanding type of mortar, which, when used in tile linings in closed vessels, will effect a slightly prestressed lining, but for this reason it must not be employed for the jointing of stoneware pipelines. Asplit "O", which is available in two colours, white and black, adheres to chemical stoneware, hitherto only found in epoxy-type cements, but has an added advantage of being rapid hardening and often it can be put into use four to eight hours after being laid. **Prodorite Ltd., Potters Lane, Wednesbury, Staffs.**

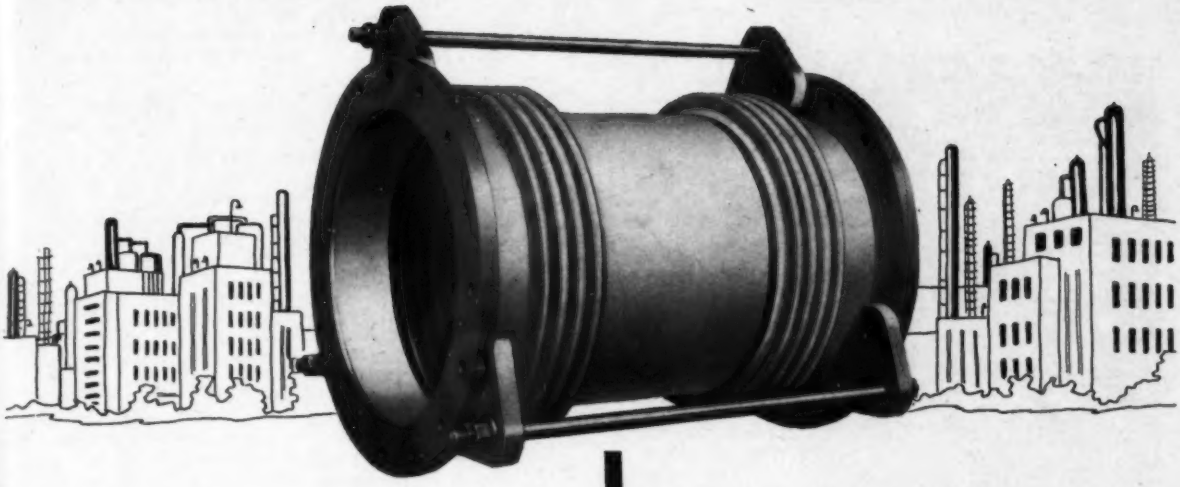
BCE 6006 for further information

Swing Couplings

J.R.H. Products inform us that all the couplings produced by the company can now be fitted with Fluon packings. Their existing range of moving pipe joints is shortly to be augmented by the addition of a new design of swing coupling suitable for pipes larger than 2 in. bore. The company's swivel and ball couplings are designed to allow for reciprocating or rotary movement on pipe joints where steam, water, air, etc., is used. They

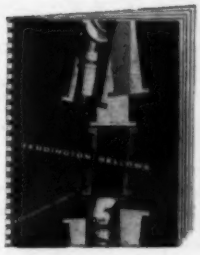
BCE 5883 for further information

The use of BELLOWS in Chemical Engineering



Wherever pipes operate under conditions of temperature and pressure, expansion joints may be required. The bellows type expansion joint has in the past few years become standard equipment, being now recognised as extremely efficient. Teddington engineers have played a leading part in the introduction of stainless steel bellows expansion joints to the chemical industry and can be relied on to co-operate fully with design and plant engineers who are confronted with pipe problems.

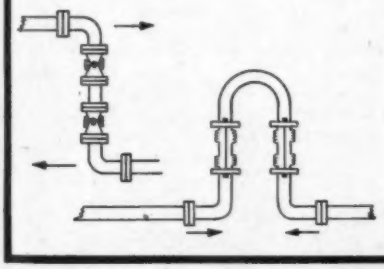
SEND FOR HANDBOOK No. M 92



Illustrated descriptions are given of the many and varied problems that Teddington Bellows Expansion Joints can overcome. If you did not secure your copy at the Engineering Exhibition, please write for one.

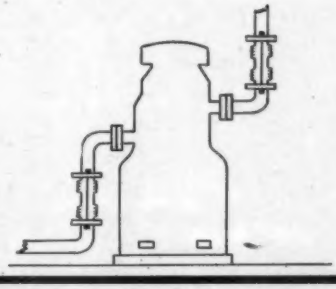
IN PIPELINES

Restrained double units operate in shear to accommodate large movements with negligible anchor leads. Two restrained double units can be used to make a very flexible, small dimension pipe loop for large expansion.



ISOLATING PIPE MOVEMENT

In the pipework connected to a pump, restrained double units fitted at right-angles to the place of vibration will operate in shear to accommodate the movement and protect the pipework.



SEALING VALVE STEMS

Bellows units provide an absolutely leak-proof seal on valve stems.

TEDDINGTON

STAINLESS STEEL FLEXIBLE BELLOWS EXPANSION JOINTS

TEDDINGTON AIRCRAFT CONTROLS LTD (*Industrial Bellows Division*) Ammanford, Carmarthenshire. Tel: Ammanford 2255

PLANT EQUIPMENT NEWS

provide the flexibility of hose combined with the durability of rigid pipe and maintain a full pipe section in all directions through 360 degrees. J.R.H. state that their swivel and ball couplings will withstand pressures up to 300 psi (steam), and temperatures up to 500°F. However, a N.P.L. Report—copies from J.R.H. Products — indicates pressures well in excess of 300 psi. **J.R.H. Products & Co. Ltd., Vale Road, Windsor, Berks.**

BCE 6007 for further information

New Transformer

A 300 kVA, three-phase, 3300/565 volt, mobile transformer substation specially designed for use in gaseous coalmines and manufactured by the Brush Electrical Engineering Co. Ltd., a member of Hawker Siddeley Industries, is claimed to be the first wholly British flame-proof dry-type transformer yet produced. It has been granted an approval certificate for use in methane-affected areas by the Safety in Mines Research Establishment at Buxton. At the recent 8th Electrical Engineers Exhibition, held in London, this equipment was awarded the silver plaque for the most outstanding industrial equipment exhibit on the basis of originality, design and construction, standard of workmanship, labour-saving attributes, and ease of operation and maintenance. It is claimed that, compared with the conventional oil-cooled unit, the new dry-type transformer, although cheaper than the imported version, represents an increase in capital outlay of some £1500. Against this fact, however, a coal-cutting machine motor re-wind costs roughly £300 and can occur as often as once every three weeks in the more highly mechanised pits. Apart from the repair cost, handling the motor to and from surface repair shops, plus the loss of coal production entailed during the stopped period, could quite easily more than double the total price of the failure. Therefore the saving experienced when using the new transformer shows a handsome return on the initial capital outlay.

For ease of manœuvring, the transformer is mounted on four flanged 12 in. dia. cast-iron wheels which are arranged to suit any track gauge between 18 in. and 36 in. Free vertical movement of approximately 2 in. is obtainable on each wheel, so that any slight unevenness in the track can be negotiated without difficulty. The general overall dimensions of the transformer are: length, 9 ft 3 in.; width, 3 ft 3 in.; height, minimum 3 ft 10 in. with 1-in. ground clearance; maximum 4 ft 2in. with 5-in. ground clearance. **Brush Electrical Engineering Co. Ltd., Loughborough, Leics.**

BCE 6008 for further information

Porous Plastics

A new porous plastic material which is tough, light and inexpensive has been announced by Pritchett & Gold and E.P.S. Co. Ltd. The new material, Vyon, which is produced from high-density polythene of the Ziegler type, has already found applications in air and liquid filtration, air fluidised powder conveying, aeration pads and as electrolytic diaphragms. Vyon is reported to have excellent chemical resistance to a wide range of aqueous solutions, and when used for liquid filtration it has the advantage of complete freedom from detachable fibres, while its smooth surfaces facilitate cleaning. In many filtration applications it can be used unsupported. Available in stock sheets up to 32 in. × 32 in. and from 0.03 in. to 0.2 in. in thickness, Vyon can be formed and welded to a variety of shapes including tubes from ¼ in. diameter. The maximum permeability (which is uniform and can be controlled in manufacture) is of the order of 50 cfm/sq. ft of air at 0.25 psi for a sheet ¼ in. thick. Our illustration shows various forms of porous Vyon sheet and fabrications **Pritchett & Gold and E.P.S. Co. Ltd., Dagenite Works, Dagenham Dock, Essex.**

BCE 6009 for further information

New Publications

The Copper Development Association now produce a publication each month (*Copper Abstracts*) which contains abstracts devoted to copper and its alloys. Subject-matter is classified under appropriate sub-headings and each abstract is serially numbered for indexing in the December issue of each year. This replaces the well-known C.D.A. Technical Survey **Copper Development Association, 55 South Audley Street, London, W.1.**

BCE 6010 for further information

The *Perkin-Elmer Instrument News*, Vol. 10, No. 2, includes a major article on a new infra-red spectrophotometer which is a double-beam optical null recording instrument designed to handle a range of analytical problems from routine identification, through complex quantitative determinations of multi-component mixtures, to studies of fundamental structure of molecules. **Perkin-Elmer Corporation, Norwalk, Connecticut, U.S.A.**

BCE 6011 for further information

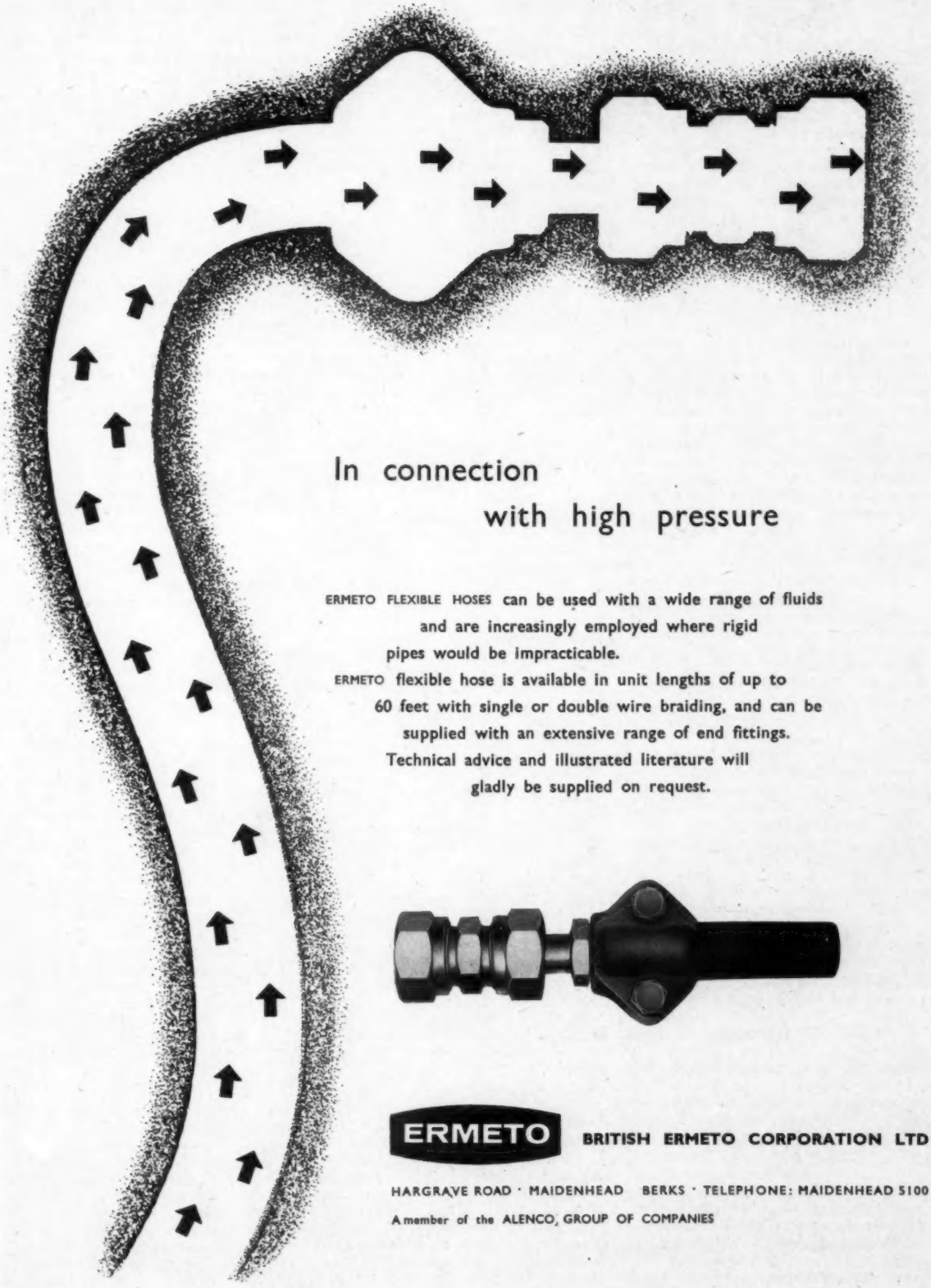
A booklet, "Properties and Applications of Silastomer Silicone Rubber", reviews applications and gives data on performance in respect of resistance to extremes of temperature, chemical inertness, electrical insulating properties and other physical properties. There is also a reference to the specification by designers of atomic energy power stations of silastomer for resilient seals on carbon dioxide - based heat - transfer systems. **Midland Silicones Ltd., 68 Knightsbridge, London, S.W.1.**

BCE 6012 for further information

The latest issue of *Wiggin Nickel Alloys* features the use of nickel in the manufacture of a tank for the transportation of phenol by road. Corrosion threatens both the life of the carrying equipment and the purity of the product. The article shows how "AT" nickel is used to protect the purity and colour of the phenol. Also featured in this issue is the use of steel plates clad with nickel or Monel in the construction of heavy items of chemical plant, high-speed steam-cleaning units and a review of high-temperature brazing techniques. Copies free on request to **Henry Wiggin Co. Ltd., Thames House, Millbank, London. S.W.1.**

BCE 6013 for further information

The National Association of Corrosion Engineers (Houston, Texas, U.S.A.) have published a report on the cathodic protection of process equipment (Publication 59-9). In this they cite 10 case histories to show ways in which cathodic protection principles can be applied to chemical process equipment. Materials and items of equipment for which case histories are reported include a Type 316 stainless-steel cooling coil in sodium hypochlorite, lead



In connection with high pressure

ERMETO FLEXIBLE HOSES can be used with a wide range of fluids and are increasingly employed where rigid pipes would be impracticable.

ERMETO flexible hose is available in unit lengths of up to 60 feet with single or double wire braiding, and can be supplied with an extensive range of end fittings.

Technical advice and illustrated literature will gladly be supplied on request.

ERMETO **BRITISH ERMETO CORPORATION LTD**

HARGRAVE ROAD · MAIDENHEAD BERKS · TELEPHONE: MAIDENHEAD 5100

A member of the ALENCO, GROUP OF COMPANIES

PLANT EQUIPMENT NEWS

pipe coils in barium chloride, mild steel in chemically pure 73% caustic, reactor cells in 10% hydrochloric acid. Type 302 stainless steel in dilute sulphuric acid-organic acid mixture, copper steam coils in zinc chloride, and copper heating coils in ammonium chloride. Criteria for protection were found to differ considerably from that generally accepted for iron and steel in substantially neutral environments. They conclude that, although process applications usually require laboratory development, cathodic protection may often provide an econocimal solution to corrosion problems.

BCE 6014 for further information

Audley Engineering have been making plug cocks since the beginning of the present century, and have specialised in the development and manufacture of lubricated taper plug valves since 1922. Audco valves are made in a wide range of engineering and chemical engineering materials of construction in sizes up to 24 in. and designed for controlling pressures from fine vacuum up to as high as 5000 psi. They are described in a brochure entitled "Audco Valves". **Audley Engineering Co. Ltd., Newport, Shropshire, England.**

BCE 6015 for further information

"Bakelite Plastics Review." The 1959 edition recently issued reviews some of the current applications of Bakelite plastics both in industry and in the home. **Bakelite Ltd., 12 Grosvenor Gardens, London, S.W.1.**

BCE 6016 for further information

Aabacas Cranes and Hoists. Mechanical Handling Equipment Catalogue 59/4. This lists single-girder cranes, underhung cranes, double-girder cranes, box lattice cranes, travelling wall cranes, special types and block and open barrel type crane crabs. There is also a section on hoists, and the catalogue includes an open invitation to directors and works managers to avail themselves of this service and put to practical use the experience and technical information available in this organisation. **Aabacas Engineering Co. Ltd., Birkenhead.**

BCE 6017 for further information

The newly issued catalogue of Autometric Pumps includes brochures on centrifugal, multi-stage, turbine, diaphragm, rotary-hand type, gear, nylon-roller vane, oscillating piston and vacuum pumps. **Autometric Pumps Ltd., Maidstone, Kent.**

BCE 6018 for further information

"The Geon Story. Everyman's Guide to P.V.C. Plastics." Geon is the trade name for polyvinyl chloride (P.V.C.) and other members of a family of vinyl plastics raw materials. The booklet outlines the nature, forms and uses of the product, primary raw materials, how it is processed and then lists typical products. First among the products discussed are units employed in chemical plant construction where there has been increasing use of rigid P.V.C. because of its resistance to so many corrosive reagents. **British Geon Ltd., Devonshire House, Piccadilly, London, W.1.**

BCE 6019 for further information

Fire Protection Association. List of Members. 31/45 Gresham Street, London, E.C.2. 42 p.p., 4s. This list is divided to give members drawn from all fields of commerce and industry and members from local and public authorities. The Association has also revised its List of Publications (gratis). The list is divided into six main sections: Building, Electricity, Industrial and Commercial Occupancies, Chemical, Fire Extinguishment and Agricultural and Forestry, with further sections detailed miscellaneous and domestic publications.

BCE 6020 for further information

Tanks & Linings have forwarded their recently issued leaflet to us which gives details of the corrosion-resistant plastics for chemical plant protection which they use in the fabrication of plant for industrial use. Entitled "Corrosion-resistant Plastics for Chemical Plant and Chemical Plant Protection", the leaflet describes the advantages offered to the chemical industry by rigid unplasticised polyvinylchloride as a constructional material for chemical plant; high-impact P.V.C.; combination sheet; metal reinforced sheet; and their Nutravic P.V.C. linings. **Tanks & Linings Ltd., Town Wharf, Droitwich, Worcestershire.**

BCE 6021 for further information

The range of Holmes-Kemp dryers has been redesigned to give higher efficiencies at lower costs. This is the reason for a newly-issued brochure by W. C. Holmes entitled "Holmes-Kemp Dryers" (Publication No. 77). The company state that, by the use of new type 4-zone heaters, it has been found that a dryer using the new heaters will, with no increase in the amount of solid desiccant used, remove approximately 10% more moisture. **W. C. Holmes & Co. Ltd., P.O. Box No. B.7, Turnbridge, Huddersfield.**

BCE 6022 for further information

A new leaflet (No. 7) in the series dealing with the use of titanium in chemical plant has been issued by I.C.I. Metals Division. Entitled "Titanium for Compressor Valve Plates and Springs", the leaflet states that because titanium combines a high strength to weight ratio with superlative corrosion resistance, it is suitable for valve plates and springs in a much wider range of operating conditions than has been practicable hitherto. A news sheet (No. G.1) also issued by I.C.I. gives details of the use made of Terylene in the reinforced plastics industries for the reinforcement of polyester and epoxy resins, both as a replacement for and as a complement to glass, because its use enables a product of improved performance to be manufactured. This news sheet should prove of interest to chemical plant fabricators, as I.C.I. state that Terylene, when used as a laminate, withstood severe chemical conditions, e.g., where the laminate was in contact with hydrofluoric acid. Copies of leaflet No. 7 from **Imperial Chemical Industries Ltd., P.O. Box 216, Birmingham 6,** and that of No. G.1 from the **Fibres Division, Hookstone Road, Harrogate, Yorkshire.**

BCE 6023 for further information

Details of their flexible furnaces and armoured heaters are given in two new leaflets by Electrothermal. The company state that their furnaces are capable of producing the concentration of heat suited to the arduous duties in heat-treatment processes; nuclear power plants; chemical and industrial plant processes; and high-temperature testing of structures. Copies of the leaflets entitled "Flexible Furnaces" and "Armoured Heaters" can be obtained from **Electrothermal Engineering Ltd., 270 Neville Road, London, E.7.**

BCE 6024 for further information

A leaflet (BA. 159) giving details of the Glitsch ballast tray, which is reputed to have higher efficiencies at very low vapour rates up to moderate vapour rates than any other tray of similar capacity, and a turndown ratio of up to 9:1 and better, has been issued by **Metal Propellers Ltd., 74 Purley Way, Croydon.**

BCE 6025 for further information

Catalogue No. 705, recently published by Birlec, describes their newly-developed range of nitrogen generators. The generators are designed to provide the right grade of nitrogen to suit a wide variety of applications and to separate nitrogen from air by the combustion of fuel, thus converting its oxygen content into carbon dioxide and water. These two waste constituents are then removed by absorption and condensation respectively. Typical running cost analyses are quoted for the production of normal commercial-grade nitrogen in the generators and for the purification cost in manufacturing special-grade nitrogen. Copies from **R. Burges, Publicity Manager, Birlec Ltd., Erdington, Birmingham, 24.**

BCE 6026 for further information

In view of the fact that suitable tipping sites for trade refuse are becoming increasingly hard to find and that waste products cannot be burned in the combustion chambers of oil- or mechanically-fired boilers, the recently issued brochure, "Scorer Refuse Destructors" by A. B. Scorer, should be of interest to those concerned with this disposal problem. **Publicity Dept., Bennis Combustion Ltd., Little Hulton, Walkden, Manchester.**

BCE 6027 for further information

PRESSURE VESSELS with a NAME

The name COCHRAN is mainly associated with marine auxiliary and industrial steam boilers of correct design and careful workmanship.

The same name attached to a pressure vessel is your guarantee of excellence.

Made throughout at Newbie Works, Annan, Dumfriesshire, COCHRAN Class I fusion welded pressure vessels are built in sizes ranging from 1′ 6″ to 14′ 0″ diameter, 5′ 0″ to 100′ 0″ in length and up to 100 tons in weight.

Send us your pressure vessel enquiries—you will find that our prices are right.

COCHRAN

Cochran & Co., Annan, Limited, Annan, Dumfriesshire. Annan 111.
34 Victoria St., London, S.W.1. ABBey 4441.

TAB/CH.630

Month's News in Brief

I.C.I.'s New Plant

The Plastics Division of Imperial Chemical Industries Ltd. is to erect a new plant near Dumfries for the manufacture of Melinex polyester film. The plant will eventually have a capacity of 2000 tons or more a year. When the new plant is in full production in 1960/61, it will be possible to do without the costly importation of American and continental polyester films. It is also certain that I.C.I. will be able to build up a profitable export trade in Melinex film.

Partnership

Imperial Chemical Industries Ltd. has entered into an agreement with the Aluminum Co. of America (ALCOA) to collaborate in the manufacture of wrought aluminium products. The two companies propose, the consent of H.M. Treasury having been obtained, to establish a new company, to be registered as Imperial Aluminium Co. Ltd., to which I.C.I.'s aluminium plants at Waunarlwydd will be transferred, and which will manufacture the wrought aluminium products now being sold by I.C.I. and any others it is subsequently decided to produce. Initially at least, these products will be sold through the existing I.C.I. selling offices. I.C.I. will hold 51% and ALCOA 49% of the capital of the new company, and I.C.I. will appoint three of the five directors, including the chairman and managing director. Control, therefore, will remain in British hands.

Agreement

Imperial Chemical Industries Ltd. and Engelhard Industries Inc., New Jersey, U.S.A., have signed agreements covering the production and sale of platinum-titanium electrodes.

Engelhard Industries Inc., which has 15 divisions and several associated companies, is one of the world's largest fabricators and refiners of precious metals, sold almost entirely for industrial and chemical purposes. Imperial Chemical Industries Ltd., pioneer of the British titanium industry, has outstanding facilities for the extraction and manufacture of this important metal and has made many notable contributions to titanium technology.

The two organisations will institute a continuing joint research programme and will pool all information acquired.

Merger

For administrative reasons, the Lime Division of I.C.I. will be merged into the Alkali Division on January 1, 1960, and will be known as the Buxton Lime Works of that Division. The general policy regarding production and sales of lime and limestone will remain unchanged, and relations with suppliers and customers will remain as at present, unless and until notification to the contrary is issued.

Gas Industry Statistics

In the year ended March 31, 1959, coal gas production was 6% lower and the quantity of coal carbonised 7% lower than in 1958. Water gas production was 2½% higher, but coke used for this purpose fell by about ½%. The quantity of oil used in water gas production increased by 10 million gallons—about 7½% higher. Purchase of surplus gas from coke ovens and oil refineries rose by 5½%, so that although the total gas production was more than 3½% lower, the amount of gas available was only 2½% less. Coke production was 7½% below production in the previous year and sales during 1958/59 were more than 5% less. Production of crude tar was 7½% less and of crude benzole 9% less. New daily gas-making capacity of 24 million cu. ft, mainly oil gasification plant, was brought into use during the quarter January to March, 1959. The total capacity of new plant brought into use during the year was 114 million cu. ft daily (total capacity of all plant in use by The Gas Industry at the end of March, 1959, was approximately 2540 million cu. ft) compared with 115 million cu. ft in the previous year. Four hundred miles of new mains were laid during the quarter, bringing the total mileage of new mains laid in the year to 1712, 12% less than in 1957/58.

Preventative Maintenance

The Harrow and Wembley Productivity Association in conjunction with the British Productivity Council are holding a one-day conference on Planned Maintenance at the Livingstone Hall, Broadway, London, S.W.1, on Tuesday, October 6, 1959. Mr. J. B. Kitchin, of I.C.I. Ltd., will take the chair and the principal speaker will be Mr. R. B. Wilson, of the European Productivity Association, a consultant on preventative maintenance. He will speak on "Maintenance as a general management problem" and "How much should you spend to prevent breakdowns?". In support, Mr. G. G. Corder, of Kodak Ltd., will give a talk on "Maintenance efficiency measurement" and Mr. H. H. Gomme, of Personnel Administration Ltd., will speak on "The best use or maintenance manpower". Further details of the conference may be obtained from The Secretary, Harrow and Wembley Productivity Association, Kodak Ltd., Harrow, Middlesex.

News Briefs

The fourth stage in the development of the South Works of Ashmore, Benson, Pease & Co. Ltd. has been completed. This stage consisted of bringing under one roof the company's machine and fitting shops, providing a working area of 160,200 sq. ft. To date about £3 million has been spent on the new works, though only a small proportion of the 120-acre site allotted to the rebuilding of the company's works has yet been used.

To ensure leak-free running over long periods of operation, 156 rotary shaft pumps and mixers in use at Esso's Fawley refinery have been fitted with Flexibox mechanical seals. The pumps and mixers (manufactured by W. H. Allen Sons & Co., Campbell & Co., Hayward-Tyler & Co. Ltd., Pulsometer Engineering Co. Ltd. and Sigmund Pumps Ltd.) handle a diverse variety of products and operate at temperatures extending from −140°F to 500°F; stuffing-box pressures cover an equally wide range.

A new heating installation for the British Aluminium Co. Ltd., at Kinlochleven, Scotland, has recently been completed by Hygrotherm Engineering. The installation is part of a plant producing Soderberg paste used in aluminium smelting furnaces and is designed to operate at 300°C or below. Automatic control of temperature is provided for mixers and hoppers. Pneumatic temperature transmitters and controllers and diaphragm-operated three-way valves are used.

Hess Products Ltd. and the chemical division of Armour Chemical Industries Ltd. have been merged under the name of Armour Hess Chemicals Ltd., of which half the share capital is controlled by Armour & Co., of Chicago, the other half being controlled by United Kingdom interests, a substantial proportion of which is held by Associated Chemicals Co. Ltd.

What is believed to be the largest all-glass chlorine cooler in existence has been delivered by QVF Ltd. to Cellulosa Argentenia Ltd., chemical manufacturers situated in Buenos Aires. The cooler has a cooling surface of 2400 sq. ft and can cool up to 40 metric tons of chlorine a day. Worth £10,924, the apparatus comprises 40 × 60 sq. ft glass coolers mounted in four vertical banks.

Monsanto's polyethylene plant at Fawley, Southampton, is in production of polyethylenes at the rate of some 10,000 tons a year. Using a high-pressure process, the Monsanto plant will produce mainly low-density polythenes for such articles as moisture-proof bags and wrappings, cable insulation material and corrosion-proof piping. The main raw material, ethylene, for the manufacture of polyethylene will be supplied from Esso's Fawley petrochemical plant.

A hydrorefining plant costing £450,000 is now in operation at the Cadishead works of Lancashire Tar Distillers. The plant, which will produce mainly low-sulphur motor benzole and a new range of tar solvents, is said to be the first of its type to be built in this country and was designed and purchased from Lurgi of Frankfurt, although the civil engineering and construction work were handled by Simon-Carves of Stockport.

W. J. Fraser & Co., of Romford, have been appointed by Eurochemic as consulting engineers on the treatment, containment and disposal of all radioactive

BCE 5886 for further information

EASY TO READ... EASY TO FIX...

Cambridge

THERMOMETERS AND THERMOGRAPHS

with MERCURY-IN-STEEL systems
for temperatures from −20°F. to 1,000°F. (or −30°C. to 600°C.)

Combined indicating and Recording Thermometer.

Index Thermometer

INDEX THERMOMETERS

as illustrated, are made in 3 dial sizes—4″, 6″ and 8″—and are available for proud or flush mounting. Boldly marked linear scales facilitate easy reading and each thermometer is guaranteed accurate to within 1% of its range. The adoption of standard patterns and ranges enables many types to be available for immediate delivery. These instruments are robust and long-lived.

THERMOGRAPHS

as illustrated, are available in standard ranges for all requirements. Of robust construction, they record accurately and clearly on 10″ circular charts. Two-pen instruments are available for recording, on the same chart, temperature and pressure, or wet and dry bulb temperatures for humidity readings. All models may be either proud or flush mounted.

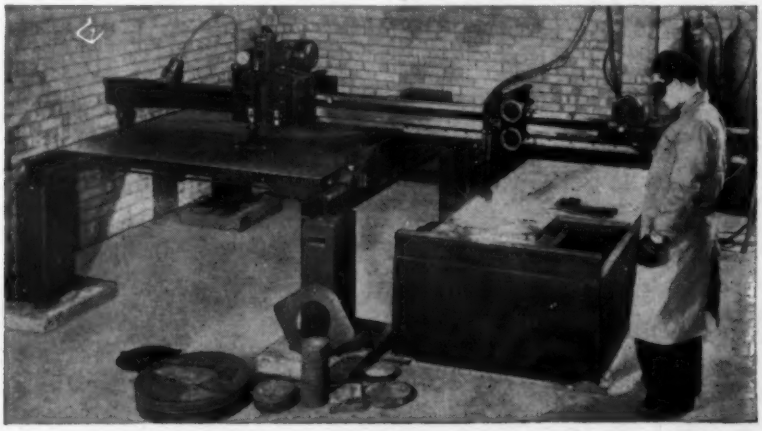
Send for LIST AR. For future publications ask for Mailing Form AR/4/59

CAMBRIDGE INSTRUMENT COMPANY LTD., 13 Grosvenor Place, London, S.W.1

TAYLOR

stainless steel plate profiling ✳

makes life easier!



Write, call or phone. Our Area Manager will be pleased to call and discuss your needs.

Immediate capacity.
Any shape, size or thickness.
We work directly from your drawings.
No templates needed.
Latest patented cutting process.
Cut face needs no machining before welding.
Quick, reliable service.
Large plate stocks always available at MILL prices, or your own stainless steel cut.

TAYLORS ALSO PROVIDE SERVICE IN

Bar blank sawing up to 14″ in dia.
Bar grinding from ¼″ to 2″ dia.
Sheet polishing 10—24 swg. up to 10′ x 4′
Tube polishing from ½″ to 2¼″ dia.

Ask for your copy of the TAYLOR STAINLESS STEEL priced stock list—new every 60 days.

TAYLOR STAINLESS METALS LTD.

A.I.D./A.R.B. approved

Buckingham Avenue · Slough · Bucks. Tel: Slough 23951 Midland Sales Office: 63 Temple Row, Birmingham 2. Tel: Midland 1430/4610

BRITAIN'S PRINCIPAL STAINLESS STEEL STOCKHOLDERS

WPP21

BCE 5887 for further information

effluents from Eurochemic's new processing plants and laboratories at Mel, Belgium.

British Oxygen Gases Ltd. have ordered a LEO 11 Automatic Office for use in their Edmonton works. LEO will be used primarily to carry out a comprehensive series of production scheduling and control tasks for the Edmonton works, but will also give general service to the remainder of the B.O.C. group.

A course of 13 lectures on newer materials for resistance to corrosion, given by authorities in their particular fields will deal with recent development in materials, metallic and non-metallic, for resistance to aqueous and high-temperature corrosion. The course, which will be held at the Battersea College of Technology, Battersea Park Road, London, S.W.11, from September 28 to October 2, 1959, should be of particular value to chemical and corrosion engineers and metallurgists who wish to obtain up-to-date information in the field of corrosion prevention.

Margam Benzole Co. Ltd. has been formed by The Steel Company of Wales Ltd. and Lincolnshire Chemical Co. Ltd., with an ordinary share capital of £150,000. The new company proposes to erect a hydrorefining plant in this country to refine coke-oven crude benzole. The plant, to be erected at Port Talbot, will draw crude benzole from The Steel Company of Wales Ltd., and will meet the growing demand for pure benzene and other aromatic products with exceptionally low sulphur contents.

A sales agreement has been signed between the American Machine & Foundry Corp. of America and William Boby & Co. Ltd., of Rickmansworth, for the American firm to market Boby electrodialysis stacks in the United States, Canada and elsewhere in the western hemisphere, excluding British territories.

Shell Chemical Co. Ltd. have announced that certain of the company's operations are now integrated into three divisions corresponding to the three main fields in which it is engaged: industrial chemicals, agriculture and plastics. These organisational changes became effective from July 1, 1959.

Laporte Chemicals Ltd., of Luton, Bedfordshire, are exhibiting for the first time at this year's S.B.A.C. Annual Flying Display and Exhibition at Farnborough. Laporte, who are the largest single producer of hydrogen peroxide in Western Europe, will feature, primarily, high test hydrogen peroxide (H.T.P.) as a compact, safe source of power for the aircraft and guided missiles industries. A stand in the outdoor static exhibition area will demonstrate live firings of a typical small rocket motor working on H.T.P. at regular intervals.

CIBA (A.R.L.) Ltd., Duxford, Cambridge, have introduced a new binder designed to hold future issues of CIBA (A.R.L.) Technical Notes. These binders are supplied for the nominal sum of 6s. 6d. each, post free.

The formation of the British Association of Corrosion Engineers has been announced. Full details and membership application forms can be obtained from the Hon. Secretary, British Association of Corrosion Engineers, 97 Old Brompton Road, London, S.W.7.

Thomas Industrial Automation Ltd., Station Buildings, Altrincham, Cheshire, have informed us that their level controller (Leveltron) is suitable for use for measuring up to 60 yards from the point of detection, and not as stated in our review of this equipment in the Plant and Equipment News section (page 430) of the July issue, 1959.

The longest fabrication ever made in Newton Chambers & Co. Ltd.'s constructional shop is an ethylene tower for use at an oil refinery at Grangemouth, Scotland. Measuring 120 ft long overall, the tower has a main body inside diameter of 5 ft and has 63 internal support rings to take numerous branches, manholes and connections. The top of the structure was made of special silicone-killed steel to withstand temperatures of −50°C. The tower has an approximate weight of 40 tons and, although the longest ever made in the company's constructional shop, they state that it is by no means the heaviest.

British Oxygen Gases Ltd. is building a new works at St. Helens, Lancashire, for the supply of oxygen and other industrial gases to that area. The works will go into production about December this year.

The new standard metric measure of 25 millilitres for use particularly by the pharmaceutical and medical professions came into operation on August 5. The Government Order legalising this additional standard is to be published as Weights and Measures (Board of Trade Standard 25 millilitres) Order, 1959/S.I.S.O., price 3d.

E. I. du Pont de Nemours & Co. are reported to have plans in hand for a major plant to produce polyethylene resin at their Victoria (Texas) works.

People in the News

The honorary degree of Doctor of Science was conferred by the **Earl of Scarbrough**, as Chancellor of Durham University, on **Hans Herman Kuehne**, a German citizen and an industrial chemist, whose specific distinction has been his part in the discovery of an economic process for manufacturing Portland cement and sulphuric acid from anhydrite.

The Minister of Power has appointed **Dr. James Burns** to be a member of the North Thames Gas Board. Dr. Burns will combine the duties of Board membership with those of his present position of chief engineer to the Board.

The appointment is announced of **Prof. John Stuart Anderson** as director of the National Chemical Laboratory, D.S.I.R. Dr. Anderson is Professor of Inorganic and Physical Chemistry at the University of Melbourne, Australia. He will succeed the retiring director, **Dr. D. D. Pratt**, and is expected to take up his new duties in October.

Prof. M. B. Donald, Professor of Chemical Engineering at University College, Gower Street, has been appointed a Co-optative Governor of the Borough Polytechnic.

Members of the Scientific Instrument Manufacturers' Association of Great Britain at their annual general meeting in July, 1959, inaugurated **Mr. L. A. Woodhead**, managing director of Cossor Instruments Ltd., as their president.

Mr. T. H. Brooke, managing director of Redferns (Bredbury) Ltd., was re-elected chairman for 1959-60 of the Plant Lining Group of the Federation of British Rubber and Allied Manufacturers. Mr. A. E. Allcock, of the Dunlop Rubber Co. Ltd., was elected vice-chairman.

Mr. E. Seymour-Semper has been elected president of the Institute of Welding for 1959/60; **Mr. W. Barr** and **Mr. E. Fuchs** are the two new vice-presidents.

The board of I.C.I. announce that **Mr. E. A. Bingen** has been elected a deputy chairman of the Board with effect on and from July 23, 1959 (in addition to Mr. S. P. Chambers and Dr. R. Holroyd), and that they have also unanimously agreed to elect **Mr. L. H. Williams** as a deputy chairman of the Board with effect on and from March 1, 1960, when **Mr. S. P. Chambers** will succeed **Sir Alexander Fleck** as chairman.

Elliott Bros (London) Ltd. announce that as from August 4, 1959, **Mr. L. Bagrit** will be chairman and chief executive, **Dr. L. L. Ross** managing director, **Mr. E. O. Herzfeld** deputy managing director and controller, and **Mr. G. C. Fairbanks** and **Cmdr. H. Pasley-Tyler,** R.N. (Ret.), assistant managing directors. **Mr. L. C. Upsdell** is now a director and secretary of the company.

Mr. A. L. Davies, managing director of Chemstrand Ltd., has announced the appointment of **Mr. P. L. Webb** as deputy managing director in charge of marketing activities.

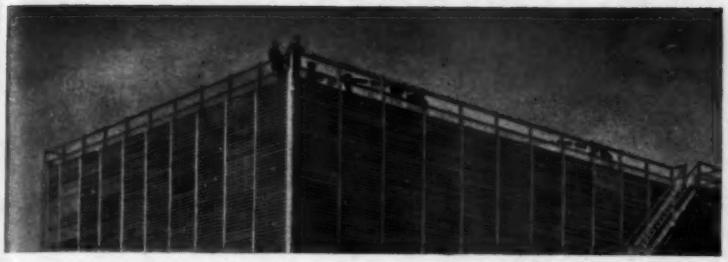
British Insulated Callender's Cables Co. Ltd. announce that **Mr. W. Fraser** has been appointed a director of the Company. The retirement of **Mr. W. G. Hendrey**, who has been a director since 1938, has also been announced.

Dr. J. T. Kendall has been appointed general manager (marketing) of Texas Instruments Ltd., replacing **Mr. K. R. Simmonds** who has resigned. **Dr. John Powell** has been appointed to the position of general manager (technical) vacated by Dr. Kendall.

Mr. L. S. Yoxall, managing director of Foxboro-Yoxall Ltd., has joined the board of directors of The Foxboro Co., U.S.A.

Mr. D. A. Monk, previously the manager of Peabody Ltd.'s burner department, has been promoted to the position of general manager.

Mr. D. C. M. Salt has been promoted director of sales and **Mr. J. M. Kershaw** director of development and market research of Monsanto Chemicals Ltd. **Dr. J. A. Gardner** is now responsible for the company's development department and **Mr. O. W. Murray** has been appointed chief engineer in place of Mr. Kershaw.



PERFORMANCE GUARANTEED

the FLUOR/HWP "COUNTERFLO" COOLING TOWER gives you a guaranteed performance backed by a detailed test procedure

INSPECTION SERVICE ENSURES CONTINUED EFFICIENCY

Once a "Counterflo" Cooling Tower is installed the H.W.P. Inspection Service will ensure that it operates at maximum efficiency throughout its life—

WRITE FOR FULL DETAILS OR RING CLE 1299

The performance of each "Counterflo" Cooling Tower is fully specified and the guarantee affords the user complete protection at no extra cost!

LOW ERECTION COSTS
LOW CAPITAL OUTLAY
LOW RUNNING COSTS

HEAD WRIGHTSON PROCESSES LTD

TEESDALE HOUSE 16/26 BALTIC STREET LONDON EC1

Offices at: P.O. Box 1595 **SYDNEY** P.O. Box 1034 **JOHANNESBURG** P.O. Box 2608 **CALCUTTA** and P.O. Box 706 **HAMBURG**

Associates in the U.S.A.: The Flour Products Company · Los Angeles 22 · New York · Chicago · Tulsa, etc.

P920

Mr. H. J. M. Stephenson has joined H. Bailey & Co. Ltd. as an executive director.

Mr. C. E. Wrangham has been appointed joint managing director of The Power-Gas Corp. Ltd.

Mr. F. Goulding (general pharmaceutical sales manager) and **Dr. A. M. Brunton** (director of medical services) have been appointed directors of Pfizer Ltd., the Kent manufacturing chemists of Folkestone and Sandwich.

Contracts

Mr. C. W. Murray, chairman and managing director of George Fletcher & Co. Ltd., of Derby, recently returned from Russia after negotiating an order valued at £150,000. The order includes 20 crystallisers and 15 vacuum pumps for use in existing beet sugar factories in Russia, and is part of an order worth £1,500,000 which was negotiated by Booker Bros. McConnell for their engineering group.

Electro-Chemical Engineering Co. Ltd., a subsidiary of Efco Ltd., have received an order from Japan to supply an electrometallurgical plant. The contract is worth more than £300,000.

As a result of negotiations with the Polish Government Agency, Centrozap, and following visits to Poland by Head Wrightson's staff, an order has been placed with The Head Wrightson Machine Co. Ltd. for two hot-dip tinning lines, valued at approximately £180,000 and designed to give an average output of 10,000 tons of tinplate a year. The new plant will treble Poland's present output of tinplate and this increase will be absorbed mainly by the Polish canning industry.

Stewarts & Lloyds Ltd. are to supply about 270 miles of 16-in.-diam. steel pipe for use in the construction of an oil pipeline in Assam, north-east India. The order is being placed by The Burmah Oil Co. Ltd., London, on behalf of Oil India Private Ltd. and with the agreement of the Government of India. The pipe to be supplied by S. & L. is worth £2 million and consists of 32,000 tons of 16-in. pipeline to A.P.I. Standard 5L X46. Delivery will be made to Calcutta at the rate of 4-5000 tons a month between September, 1959, and March, 1960. The pipeline will be manufactured at S. & L.'s Clydesdale Works.

Changes

After more than 25 years at Ingate Place, London, S.W.8, Stream-Line Filters Ltd. have moved to new premises at Guildford, the headquarters of the parent company, Vokes Ltd. Their new address is Henley Park, Normandy, Nr. Guildford, Surrey. Tel. Normandy 3311/2/3.

Interlas Ltd., a new company with its registered office at 232 Bromham Road, Bedford, has been formed to import and distribute exclusive welding plant and accessories throughout the United Kingdom. It is a joint enterprise of the continental welding supplies firm of Interlas N.V., of Soesterberg, Holland, whose managing director, Mr. H. C. van Arum, becomes chairman, and Mr. Eric Courtney managing director. Offices, stores and dispatch departments will shortly be opened in Ampthill, Bedfordshire, but for the time being business is being conducted from the registered office.

The new Firth Cleveland Group headquarters are now at Stornoway House, St. James's, London, S.W.1, having been transferred there from Cleveland Row after an official opening ceremony by Lord Beaverbrook. Tel.: WHItehall 2166.

Baldwins have changed their trading name to Baldwins Industrial Controls, a title which more clearly defines the services which they offer to industry today from that of 1949, when they were primarily engaged in the manufacture of nucleonic thickness gauges.

Evershed & Vignoles Ltd. announce that their Scottish area office has moved into larger accommodation. The new address is 30 Rutland Square, Edinburgh, 1. Tel.: Fountainbridge 3056.

With the acquisition of the lease of 14 Grosvenor Place, the Cambridge Instrument Co.'s headquarters have been extended. The official address of the company will remain 13 Grosvenor Place.

Elga Products Ltd.'s ion exchange division have moved to a new factory at Lane End, Bucks. Headquarters, research and service regeneration are now established at this address. Tel.: Lane End 396.

Badger Ltd. announce that their new address is Lincoln's Inn Chambers, 40-43 Chancery Lane, London, W.C.2. Tel.: HOLborn 0084.

Cambrian Wagon & Engineering Co. Ltd., a subsidiary of Powell Duffryn Ltd., has changed its name to Powell Duffryn Engineering Co. Ltd. Over recent years the company has established itself in the manufacture of equipment for the petroleum, chemical and allied industries and in a wide field of heavy precision and structural engineering

Coming Events

August 30-September 6. *At Munich, Germany.* 17th International Congress of Pure and Applied Chemistry and 20th Conference of International Union of Pure and Applied Chemistry.

September 2-9. *At York.* British Association for the Advancement of Science's 121st Annual Meeting.

September 5-11. *In Warsaw, Poland.* International Conference on the Application of Large Radiation Sources in Industry.

September 8-18. *At Olympia, London, W.*14. The Packaging Exhibition.

September 10-11. *At Statler Hilton Hotel, New York, U.S.A.* The 2nd International Air Pollution Congress organised by the American Society of Mechanical Engineers.

September 14-19. *At University of Durham, Newcastle upon Tyne.* Symposium on the Treatment of Waste Waters.

September 17. *At the Connaught Rooms, London, W.C.*2. One-day Conference on "Operational Research at Work". Organised by B.I.M., 80 Fetter Lane, London, E.C.4.

September 18. *At Queen Mary College, Mile End Road, London, E.*1. National Committee for High-speed Photography Conference.

September 20-23. *At Old Swan Hotel, Harrogate, Yorks.* Society of Glass Technology's 1959 Meeting.

September 21-25. *At the Clarendon Laboratory, Oxford.* Sixth Annual Refresher Course on "Current Practice in Fuel Efficiency". Organised by N.I.F.E.S., 181 King's Road, Ealing.

September 24-26. *At William Beveridge Hall, Senate House, University of London, W.C.*1. Joint Conference of Hydrocarbon Research Group of Institute of Petroleum and Committee E-14 of the American Society for Testing Materials.

October 9-10. *At Southport.* Two-day Conference on "Industrial Technical Organisation". Organised by Institution of Rubber Industry, 4 Kensington Palace Gardens, London, W.8.

October 17-25. *At Düsseldorf, Germany.* Plastics International Fair.

October 20-23. *At Seymour Hall, London.* Clean Air International Conference and Exhibition.

November 23. National Safety Campaign Week.

Looking Ahead—1960

The First Commercial and Industrial Refrigeration Exhibition will be held at the Old Hall of the Royal Horticultural Society from February 15-17.

The Fire Protection Association are staging a National Fire Protection Conference in February. The conference will be held in London and will be open to the general public.

The Engineering Materials and Design Exhibition and Conference, the first of its kind in this country, will take place at Earls Court from February 22-26.

The Ninth Electrical Engineers' Exhibition will be held at Earls Court, London, from April 5-9.

The First International Compressed Air and Hydraulics Exhibition and the 2nd European Fluid Power Conference wil take place from April 25-29 at Olympia, London.

The Second European Symposium on Chemical Reaction Engineering will be held in Amsterdam from April 27-29 under the auspices of the European Federation for Chemical Engineering.

The Duke of Edinburgh has consented to become Patron of the Instruments, Electronics and Automation Exhibition which will be held at Olympia, London, in May.

The 1960 International Congress on the Technology of Plastics Processing will take place in Amsterdam from October 10-12 and will be sponsored by the Association for the Advancement of the Knowledge of Materials, the Royal Institute of Engineers and the Royal Netherlands Chemical Federation.

An International Symposium on Distillation, organised by The Institution of Chemical Engineers to be held at Brighton, May 4-6.